

Principles and Practice
OF
AGRICULTURAL ANALYSIS

A Manual for the Study of Soils, Fertilizers, and
Agricultural Products

For the Use of Analysts, Teachers, and Students of Agricultural
Chemistry

2ND EDITION, REVISED AND ENLARGED

VOLUME I.

SOILS

BY HARVEY W. WILEY, A.M., Ph.D.

EASTON, PA.
THE CHEMICAL PUBLISHING CO.
1906

COPYRIGHT, 1906, BY HARVEY W. WILEY

PREFACE TO VOLUME FIRST.

In this volume I have endeavored to place in the hands of teachers and students of Agricultural Analysis, and of analysts generally, the principles which underlie the science and art of the analysis of soils and the best approved methods of conducting it.

In the prosecution of the work I have drawn freely on the results of experience in all countries, but especially in the matter of the physical examinations of soils, of this country. Science is not delimited by geographic lines, but an author is not to be blamed in first considering favorably the work of the country in which he lives. It is only when he can see nothing of good outside of its own boundaries that he should be judged culpable. It has been my wish to give full credit to those from whose work the subject-matter of this volume has been largely taken. If, in any case, there has been neglect in this matter, it has not been due to any desire on my part to bear the honors which rightfully belong to another. With no wish to discriminate, where so many favors have been extended, especial acknowledgments should be made to Messrs. Hilgard, Osborne, Whitney, and Merrill, for assistance in reading the manuscript of chapters relating to the origin of soils, their physical properties, and mechanical analysis. With the wish that this volume may prove of benefit to the workers for whom it was written I offer it for their consideration.

H. W. WILEY.

*Washington, D. C.,
Beginning of January, 1895.*

Preface to the Second Edition of Volume I.

So rapid has been the advance of agricultural science that in the preparation of the second edition of this volume it has been found necessary to practically rewrite it. A considerable part of the contents of the first edition of this volume relating as much, if not more, to fertilizers than to soils, has been transferred to the second volume, but new matter more than equivalent thereto in bulk has been inserted. The latest improved methods have been described, in so far as they are based on new principles or have secured better results. An attempt has been made to bring out more fully the principles of procedure involved in order that the present volume might not only mirror the latest advances in science, but also, to some extent, reflect the philosophy of method and practice. To this end, many of the older methods, long out of vogue, are retained, because in them are found the beginnings of fundamental procedures which serve to unify the processes of analysis and render more intelligible the modern methods.

The cordial reception accorded to the first edition of this manual encourages me to believe that the present volume will also be given a like welcome.

H. W. WILEY.

*Washington, D. C.,
October 15, 1906.*

Table of Contents of Volume First.

PART FIRST.

Introduction, pp. 1-17.—Definitions; Origin of soil; Chemical elements in the soil; Atomic weights; Properties of the elements; Relative abundance of the elements; Minerals occurring in rocks; Classification of minerals.

Rocks and Rock Decay, pp. 18-32.—Types of rocks; Microscopical Structure of Rocks; Composition of rocks; Color of rocks; Kinds of rocks; Aqueous rocks; Eolian rocks; Classification of sedimentary rocks; Metamorphic rocks; Eruptive rocks.

Genesis of Soils, pp. 32-60.—Decay of rocks; Action of freezing and thawing; Action of Glaciers; Effect of latitude on decay; Action of water; Action of vegetable life; Action of worms and bacteria; Action of air; Classification of soils; Qualities and kinds of soils; Humus; Artificial humus; Action of high temperature on humus; Functions of humus; Soil and sub-soils.

PART SECOND.

Samples of Analysis, pp. 61-85.—General principles; General directions for sampling; Method of Hilgard; Official French method; Caldwell's, Wahnschaffe's, Peligot's, and Whitney's methods; Samples for moisture; Samples for permeability; Samples for staple crops; Method of the Royal Agricultural Society; Method of Grandeau; Method of Official Agricultural Chemists; Method of Lawes; Sampling in relation to special crop; Instruments for taking samples; Principles of success in sampling.

Treatment of Sample in the Laboratory, pp. 85-92.—Preliminary examination; Air drying; Treatment of loose soils; Treatment of compact soils; Miscellaneous methods.

PART THIRD.

Physical Properties of Soils, pp. 93-99.—Color of soils; Odoriferous matters in soils; Specific Gravity; Volume of soil; Apparent specific gravity; Determination of weight per acre.

Relation of Soil to Heat, pp. 99-101.—Sources of soil heat; Specific heat; Influence of heat; Influence of moisture; Absorption of solar heat.

Determination of Specific Heat, pp. 101-110.—General principles; Method of Pfaunder; Method of Lang; Variation in specific heat.

Soil Thermometry, pp. 110-115.—General principles; Frear's method of stating results; Method of Whitney and Marvin.

Applications of Soil Thermometry, pp. 116-117.—Absorption of heat; Conductivity of soils for heat.

Cohesion and Adhesion of Soils, pp. 117-125.—Behavior of soil after wetting; Methods of determining cohesion and adhesion; Cementation tests; Briquette machine; Method of Heinrich; Adhesion of soil to wood and iron; Flocculation.

Absorption by Soils, pp. 125-139.—General Principles; Summary of data; Cause of Absorption; Deductions of Warrington, Way and Armsby; Selective absorption of potash; Relation of absorptive power to fertility; Influence of surface area; Effect of removal of organic matters; Importance of soil absorption; Methods of determining absorption; statement of results; Preparation of salts for absorption.

Relations of Porosity to Soil Moisture, pp. 140-164.—Definition of porosity; Influence of drainage; Capacity of soil for moisture; States of water in soil; Surface tension; Determination of porosity; Volume of interstitial space; Porosity of soil to air; Capacity of soil for water; Wolff's and Wanschaffe's method; Petermann's method; Mayer's method; Volumetric Determination; Accuracy of results; Wollny's method; Heinrich's method; Effect of pressure on water capacity; Coefficient of evaporation; Determination of capillary attraction; Descending capillarity; Determination of coefficient of evaporation; Wolff's method; Water given off in a water-free atmosphere; Porosity of soil for gases; Determination of permeability in the field.

Movement of Water Through Soils: Lysimetry, pp. 164-180.—Porosity in relation to water movement; Methods of water movement; Capillary movement of water; Lateral Capillary flow; Causes of water movement; Effect of salts on water movement and soil moisture; Preparation of soil extracts; Lysimetry; Relative rate of flow of water through soils; Measurement of rate of percolation; Percolation through a soil *in situ*; Apparatus of Deherain; Importance of analysis of drainage waters.

PART FOURTH.

MECHANICAL ANALYSIS.

Purpose of Mechanical Analysis, pp. 181-184.—General principles; Suspended colloids; Effect of non-electrolytes; Separation of colloids.

The Flocculation of Soil Particles, pp. 184-195.—Relation of flocculation to mechanical analysis; Illustration of flocculation; Effect of potential of surface particles; Quincke's theory; Destruction of floccules; Suspension of clay in water; Effect of chemical action; Theory of Barus; Theory of Rowland; Practical Application.

Methods of Separating Soil Particles, pp. 195-200.—Separation into par-

ticles of standard size; Separation in a sieve; Sifting with water; German method; Classification by sieve analysis; Nomenclature of silt particles.

Separation of Soil Particles by Subsidence, pp. 200-226.—Classification of methods of silt analysis; Methods depending on subsidence of soil particles; Methods of Kühn, Knop, Wolff, Moore, Bennington, Gasparin, Osborne, Schloesing, the Italian, French and Belgian processes and methods of Williams-Fadejeff, Gawabowski, and Nefedof.

Separation of Soil Particles by a Liquid in Motion, pp. 226-310.—General principles; Nöbel's Apparatus; Method of Dietrich; Method of Masure; Method of Schöne; Mayer's method; Osborne-Schöne method; Statement of results; Berlin-Schöne method; Hilgard's method; Colloidal clay; Properties of pure clay; Separation of fine sediments; Weighing sediments; Classification of results; Comparison of methods; Mechanical determination of clay; Effect of boiling on clay; Acceleration of sedimentation; Centrifugal elutriator; Sjollem's method; Measuring diameter of silt groups; Methods of tabulation; General conclusions; Distribution of soil ingredients; Percentage of silt classes; Interpretation of silt analysis; Number of soil particles; Mineralogical examination of silt; Microscopical examination; Petrographic microscope; Forms and dimensions of particles; Silt classes; crystal angles; Refractive index; Polarized light; Staining silt particles; Cleavage of soil particles; Microchemical examination of silt particles; Petrographic examination of silt particles; Separation of silt particles by specific gravity; Separation with a magnet; Abundance of mineral compounds in soils; Color and transparency; Value of silt analyses.

PART FIFTH.

Estimation of Gases in Soils, pp. 311-329.—Relation of soil composition to gases; Carbon dioxide; Aqueous vapor; Methods of Study; Maximum hygroscopic coefficient; Absorption of aqueous vapors; Absorption of oxygen and air; General method of determining absorption; Special methods; Diffusion of carbon dioxide; Statement of results; General conclusions.

PART SIXTH.

Chemical Analysis of Soils, pp. 330-385.—Preliminary considerations; Order of examination; Reaction of the soils; Determination of water in the soils; Different methods employed; General conclusions; Estimation of organic matter in soils; Estimation of humus; Comparison of methods; Organic hydrogen; Organic oxygen; Free humic acids; Estimation of soil acidity; Nature of soil acidity; Estimation of carbonates in arable soils.

Digestion of Soils with Solvents, pp. 385-400.—General considerations; Treatment with water; With water saturated with carbon dioxide; With water containing ammonium chlorid; With water containing acetic acid; Treatment with citric acid; With hydrochloric acid; With nitric acid;

With hydrofluoric and sulfuric acids; Strength of the acid; Influence of time of digestion; Digestion vessels; Methods employed; Agitation and constant temperature; Digestion with hydrofluoric acid; Summary of conclusions.

Determination of the Dissolved Matter, pp. 400-480.—Hilgard's methods; Petermann's method; Analysis of the insoluble residue; Wolff's method; Belgian methods; Bulk analysis; Conditions of potash in soils; French method for potash; Potash soluble in concentrated acids; Soluble in dilute acids; Estimation as platinochlorid; German Station methods; Raulin's method; Russian method; Italian method; Smith's method; International method; Tatlock's method; Moore's method; Estimation of total alkalies and alkaline earths; French method for lime; Estimation of actual calcium carbonate; Estimation of active calcareous matter; Russian method for lime; Assimilable lime; German lime method; Estimation of magnesia; Estimation of manganese; Estimation of iron; Estimation of phosphoric acid; Estimation of sulfuric acid; Estimation of chlorine; Estimation of silica; Estimation of titanium; Simultaneous estimation of different elements; Estimation of kaolin in soils.

Estimation of Nitrogen in Soils, pp. 480-507.—Nature of nitrogenous principles; Early method of Official Agricultural Chemists; The official Kjeldahl method; Hilgard's method; Moist combustion method of Müller; Arnold and Wedemeyer's method; Soda-lime method; Treatment of soil containing nitrates; Volumetric method with copper oxid; Estimation of ammonia; Amid nitrogen; Volatile nitrogenous compounds; General conclusions.

Methods of the Official Agricultural Chemists for Soil Analysis, pp. 508-518.

PART SEVENTH.

Activity of Nitrifying Organisms in the Soil, pp. 519-569.—Organic nitrogen; Development of nitrous and nitric acids; Conditions of nitrification; Nitrifying power of soils; Effect of potassium salts on rate of nitrification; Production of nitrous and nitric acids; Production of ammonia by microbes; Order of oxidation; Nitrification of ammonia; Sampling tubes; Collecting samples; Culture medium; Temperature; Testing for nitrous and nitric acids; statement of results; Effect of acidity on nitrification; Apparatus and manipulation; Distribution of nitrifying organisms; Depth at which organisms live; Mineral gelatin; Isolation of nitrous and nitric ferments; Dilution method; Classification of organisms; Azotobacter; Sterilization; General Conclusions.

Estimation of Nitrous and Nitric Acid in Soils, pp. 569-572.—Classification of methods; Relative merit of methods; Extraction of nitric acid.

PART EIGHTH.

Special Examination of Waters, pp. 573-594.—Sampling irrigation waters; Total solid matter; Estimation of chlorin; Estimation of carbon dioxide; Estimation of carbonates and bicarbonates; Extraction of soil water; Phosphoric acid in soil water; Colorimetric estimation of phosphoric acid.

Special Treatment of Peat Soils, pp. 594-609.—Sampling; Water content; Organic carbon and hydrogen; Total volatile matter; Estimation of sulfur; Estimation of phosphoric acid; Estimation of humus; Special study of soluble matters in peat soils; Ether extract; Acid extract; Acidity of peat soils.

Rare Constituents of Soil, pp. 609-618.—Estimation of copper; Estimation of lead; Estimation of zinc; Estimation of strontium; Estimation of boron; Estimation of titanium.

Illustrations to Volume First.

	Page
Plate I-III, figures 1-6. To face	18
Figure 1. Microstructure of basalt	18
" 1. Microstructure of diabase	18
" 3. Microstructure of quartzite	18
" 4. Microstructure of crystalline limestone	18
" 5. Microstructure of Gneiss	18
" 6. Microstructure of Granite	18
" 7. Microstructure of sandstone	18
Plate, figure 8. View on the broad branch of Rock Creek, Washington, D.C., to face	37
Figure 9. King's Soil Sampler	79
" 10. Sampling auger	81
" 11. Regnault's apparatus for determining the specific heat of soils	103
" 12. Lang's apparatus for specific heat	109
" 13. Soil Thermometer	113
" 14. Apparatus for powdering stone	118
" 15. Mold for making briquettes	119
" 16. Machine for pressing briquettes	120
" 17. Machine for testing briquettes	122
" 18. Diagram of breaking-point of briquettes	123
" 19. Fillitz apparatus for determining absorption of salts by soils	135
" 20. Müller's apparatus to show absorption of salts by soils	135
" 21. King's aspirator	146
Plate, figure 22. Capacity of the fine soil for holding moisture. Method of Wolff, modified by Wahnschaffe, to face	148
Figure 23. Fuelling's apparatus	152
" 24. Apparatus to show capillary attraction of soils for water	158
Plate, figure 25. Apparatus for determining coefficient of evaporation, to face	160
Figure 26. Method of Heinrich	164
" 27. Method of Welltschowsky	173
" 28. Ground plan and vertical section of lysimeters and vaults, showing posi- tion of the apparatus	177
Plate, figure 29. Deherain's apparatus for collecting drainage water, to face	178
Figure 31. Knop's silt cylinder	205
" 32. Siphon cylinder for silt analysis	206
" 33. Benningsen's silt flasks	211
" 34. Nöbel's elutriator	227
" 35. Dietrich's elutriator	229
" 36. Masure's silt apparatus	230
" 37. Schöne's elutriator	232
" 38. Schöne's elutriator outflow tube	233
" 39. Schöne's elutriator, arrangement of apparatus	235
" 40. Schöne's apparatus for silt analysis, modified by Mayer	241
" 41. Hølgard's churn elutriator	248
" 42. Improved Schöne's apparatus with relay	249
" 43. Shaker tray containing bottles, to face	269
" 44. Mechanical shaker used in preparing soils for mechanical analysis	269
" 45. Centrifugal machine used in mechanical analysis of soils	270
" 46. Yoder's centrifugal elutriator	271

Figure 47.	Boile for centrifugal elutriator	272
" 48.	Microscope for silt examination	284
" 49.	Relative sizes of silt particles, to face	286
" 50 to 67 inclusive,	microchemical examination of silt particles, plates to face	290, 292, 293
" 68.	Machine for making mineral sections	295
" 69.	Thoulet's separating apparatus	302
" 70.	Harada's apparatus	305
" 71a, 71b, 71c,	Brögger's apparatus	306
" 72.	Apparatus of Wülfing	307
" 73.	Schloesing's soil-tube for collecting gases	320
" 74.	Schloesing's apparatus for collecting gases from soil	322
" 75.	Schloesing's apparatus for determination of carbon dioxide	323
" 76.	Apparatus for chromic acid method	355
" 77.	Tacke's apparatus	373
" 78.	Knorr's apparatus for the determination of carbon dioxide	380
" 79.	Bernard's calcimeter	382
" 80.	Shaking machine for soil extraction	394
" 81.	Smith's muffle for decomposition of silicates	426
" 82.	Apparatus by Sachsse and Becker	449
" 83.	Sampling tubes, to face	528
" 84.	Hood for seeding cultures, to face	529
" 85a, 85b,	Nitrous and nitric organisms in soils, to face	550
" 86.	Sterilizing oven	562
" 87.	Autoclave sterilizer	564
" 88.	Arnold's sterilizer	565
" 89.	Thermostat	566
" 90.	Colorimeter	591
" 91.	Apparatus for sulfur	599
" 92.	Apparatus for boric acid	612

PART FIRST

INTRODUCTION

1. **Definitions.**—The term soil, in its broadest sense, is used to designate that portion of the surface of the earth which has resulted from the disintegration of rocks and the decay of plants and animals, and which is suited, under proper conditions of moisture and temperature, to the growth of plants. It consists, therefore, chiefly of mineral substances, together with some products of organic life, and of certain living organisms whose activity may influence vegetable growth either favorably or otherwise. The soil also holds varying quantities of gaseous matter and of water, which are important factors in its functions. The soil cannot be regarded as dead matter, but as a living organism exhibiting many most remarkable biological phenomena.

2. **Origin of Soil.**—Agriculturally considered, the soil proper is the older and more thoroughly disintegrated superficial layer of the earth, which has been longest exposed to weathering and the influences of organic life. It varies from a few inches to several feet in depth. The term subsoil is usually applied to a layer of soil beginning at the usual depth of cultivation and of a thickness of from six to nine inches. The surface of demarcation of change of color is sometimes regarded as the upper superficial boundary of the subsoil. The terms soil and subsoil are therefore not always used with the same relative signification. The subsoil is not as a rule so thoroughly disintegrated as the soil, since it is protected in a measure by the overlying material. It usually contains less organic matter than the soil. There is a freer circulation of air in the soil than in the subsoil, and the metallic elements usually exist in the upper layers as higher oxids. There is usually a notable difference in color between the soil and subsoil, and frequently a very sharp color line separates the two.

Geologically considered, the soil is that portion of the earth's

crust which has been more or less thoroughly disintegrated by weathering and other forces from the original rock formations, or from the sedimentary rocks, or from the unconsolidated sedimentary material. The soil has, therefore, the same essential constitution as the general mass of the earth, except that this debris has been subjected to the solvent action of water and the influence of organic life.

Preliminary to the proper understanding of the methods of the analysis of soils, there should be some definite knowledge concerning the composition of the earth's crust, so that the analyst may understand more thoroughly the origin and nature of the material he has to deal with, and thereby be better equipped for his work.

3. The Chemical Elements Present in the Soil.—The chemical elements present in the soil are naturally some or all of those which were present in the original rocks. For analytical purposes relating to agriculture, it is not necessary to take into account the rare elements which may occur in the soil, but only those need be considered which are present in some quantity and which enter as an important factor into plant growth or modify in some manner its physical properties. Of the whole number of chemical elements less than one-third are of any importance in soil analysis. These elements may be grouped into two classes, the non-metals, and the metals as follows:

Non-metals		Metals	
Oxygen,	Chlorine,	Aluminum,	Iron,
Silicon,	Phosphorus,	Calcium,	Manganese,
Carbon,	Nitrogen,	Magnesium,	Barium,
Sulfur,	Fluorine,	Potassium,	Titanium,
Hydrogen,	Boron,	Sodium,	Chromium.

4. Atomic Weights.—For the purpose of facilitating the calculation of results the latest revised table of atomic weights is given below.¹ All the known elements are included in this table for the convenience of analysts who may have to study some of the rarer elements in the course of their work.

¹ This table represents the latest and most trustworthy results reduced to a uniform basis of comparison with oxygen = 16 as starting point of the system.

TABLE OF ATOMIC WEIGHTS OF THE ELEMENTS¹

Name.	Symbol.	Atomic weight.	Name.	Symbol.	Atomic weight.
Aluminum	Al	27.1	Neon	Ne	20.
Antimony	Sb	120.2	Nickel	Ni	58.7
Argon	A	39.9	Nitrogen	N	14.04
Arsenic	As	75.	Osmium	Os	191.
Barium	Ba	137.4	Oxygen	O	16.
Bismuth	Bi	208.5	Palladium	Pd	106.5
Boron	B	11.	Phosphorus	P	31.
Bromine	Br	79.96	Platinum	Pt	194.8
Cadmium	Cd	112.4	Potassium	K	39.15
Cesium	Cs	132.9	Praseodymium	Pr	140.5
Calcium	Ca	40.1	Radium	Ra	225.
Carbon	C	12.	Rhodium	Rh	103.
Cerium	Ce	140.25	Rubidium	Rb	85.5
Chlorine	Cl	35.45	Ruthenium	Ru	101.7
Chromium	Cr	52.1	Samarium	Sm	150.3
Cobalt	Co	59.	Scandium	Sc	44.1
Columbium	Cb	94.	Selenium	Se	79.2
Copper	Cu	63.6	Silicon	Si	28.4
Erbium	Er	166.	Silver	Ag	107.93
Fluorine	F	19.	Sodium	Na	23.05
Gadolinium	Gd	156.	Strontium	Sr	87.6
Gallium	Ga	70.	Sulfur	S	32.06
Germanium	Ge	72.5	Tantalum	Ta	183.
Glucinum	Gl	9.1	Tellurium	Te	127.6
Gold	Au	197.2	Terbium	Tb	160.
Helium	He	4.	Thallium	Tl	204.1
Hydrogen	H	1.008	Thorium	Th	232.5
Iodine	I	126.97	Thulium	Tm	171.
Iridium	Ir	193.	Tin	Sn	119.
Iron	Fe	55.9	Titanium	Ti	48.1
Krypton	Kr	81.8	Tungsten	W	184.
Lanthanum	La	138.9	Uranium	U	238.5
Lead	Pb	206.9	Vanadium	V	51.2
Lithium	Li	7.03	Xenon	Xe	128.
Magnesium	Mg	24.36	Ytterbium	Yb	173.
Manganese	Mn	55.	Yttrium	Yt	89.
Mercury	Hg	200.	Zinc	Zn	65.4
Molybdenum	Mo	96.	Zirconium	Zr	90.6
Neodymium	Nd	143.6			

PROPERTIES OF THE ELEMENTS.

Following is a brief description of the most important elements occurring in the earth's crust in respect of their relations to agriculture.

¹ Report of International Committee on Atomic Weights, Journal of the American Chemical Society, 1905, 27 : 1-7.

5. **Oxygen** exists in the free gaseous state in the atmosphere of which it constitutes about one-fifth by bulk, and in combination with other elements it forms nearly half the weight of the solid earth, and eight-ninths by weight of water. It enters into combination with most of the other elements, forming what are known as oxids, and with many of the elements it unites in several proportions, forming oxids of different composition. Combined with silicon, carbon, sulfur, and phosphorus, it forms an essential part of the silicates, carbonates, sulfates and phosphates, most of which are very abundant and all of which are very widely distributed in the earth's crust. In this form it is exceedingly stable and is rarely set free. With the exception of the oxids of silicon and iron these oxids seldom occur uncombined with the metals as constituents of rocks or soils. The oxids of iron very commonly occur as such in rocks and soils, and play a very important part in organic life. The several oxids of iron very frequently determine the color of soils; as the iron in a soil is more or less oxidized, or as it is exposed more or less to access of air, the color of the soil changes. These oxids of iron also play an important part in the absorptive capacities of soils for moisture and other physical conditions of soils, and also in the oxidation of organic matters in the soil. Many organic substances, and even the roots of growing plants when deprived of free access of air, can readily secure oxygen from the iron oxid, thus reducing the iron to a lower form of oxidation, the oxygen being used for the oxidation of the organic matter or for the needs of the growing plant; while the lower oxid of iron can easily take up the oxygen of the air and again be converted into a higher oxid ready again to give up a part of its oxygen and thus serve as a carrier.

6. **Silicon** never occurs in the free state, but combined with oxygen it forms silica, which constitutes free or in combination, more than one-half of the earth's crust. The oxid of silicon occurs in the very common form of quartz, and as silicate of alumina, lime or magnesia silicon forms an essential part of many minerals, such as the feldspars, amphiboles, pyroxenes and the micas, besides being an essential ingredient of many other minerals. Silica is relatively very slightly affected by the ordinary forces concerned in the decay of rocks, and even after the crystals of

feldspars, micas and other common minerals occurring in rocks have been disintegrated it remains as hard grains of sand, forming the bulk of most soils. By far the larger part of silicon in soils is in the form of grains of quartz more or less modified. This form of silica is probably chemically inert in regard to plant growth, but it plays a very important part in the physical structure of soils in its relations to plant nutrition.

7. **Carbon** as an elementary substance occurs as diamond and graphite and in an impure form as anthracite and bituminous coals. In peats and mucks carbon is the chief constituent. This substance is also contained in the organic matters of the soil known as humus, and the relation of the carbon to nitrogen often throws important light upon the amount and character of the nitrogenous matters. The humus content of the soil also affects its relation to water and to the absorption, retention and radiation of heat. In composition with oxygen it forms the chief food of growing plants, the carbon of the carbon dioxide of the air being elaborated into the tissue of the plants and the oxygen returned to the atmosphere. The content of carbon dioxide in the air is from three to five parts per 10,000 by volume. As a constituent of carbonates this element helps to form some of the most important ingredients of the earth's crust; namely, limestones, marbles, dolomites, etc., and as a result of organic activity it is found in the shells of the crustaceans. The calcareous matters of the soil, that is, the carbonates of lime therein found, are of the highest importance from an agricultural point of view. They not only favor the process of converting nitrogenous bodies into forms suitable for plant food, but also exert a most potent influence on the physical state of the soil and its capacity for holding water and permitting its flow to the rootlets of the plant.

8. **Sulfur** occurs in nature in both the free and combined state. In the free state it is found in volcanic regions such as Sicily, Iceland, and the western United States. Its usual form of occurrence is in combination with the metals to form sulfides, or with oxygen and a metal to form sulfates. Sulfur and iron combine to form iron pyrites or iron disulfide (FeS_2), while sulfur, oxygen, and calcium are found in gypsum, an important fertilizing compound.

Sulfur plays an important part in the nourishment of plants, being found in them both as sulfuric acid and in organic compounds; it is an essential constituent of both animal and vegetable protein and is thus intimately associated with one of the most important classes of foods.

9. Hydrogen is a colorless, invisible gas, without taste or smell. It occurs free in small proportions in certain volcanic gases, and in natural gas, but its most common form is in combination with oxygen as water (H_2O), of which it forms 11.19 per cent. by weight. It also occurs in combination with carbon to form the hydrocarbons, such as the mineral oils (petroleum, etc.) and gases. Hydrogen is of no importance to agriculture in a free state, but water is the most important and necessary of all plant foods.

10. Chlorin occurs free in nature only in limited amounts in volcanic vents. Its most common form is in combination with hydrogen, forming hydrochloric acid, or with the metals to form chlorids. It combines with sodium to form sodium chlorid or common salt ($NaCl$), which is the most abundant mineral ingredient in sea water and which can usually be detected in rain and ordinary terrestrial waters. In this form, also, it exists as extensive beds of rock salt, which is mined for commercial purposes.

Chlorin is found uniformly in plants and may be regarded as a common constituent thereof. Common salt applied to a soil modifies its power of attracting and holding water but it cannot be said to have any marked fertilizing value. In excess it proves highly injurious and even fatal to vegetation.

11. Phosphorus never occurs in nature in a free state but exists in combination in greater or less quantities in all soils and in many minerals. Its combinations are also found in large deposits of mineral known as phosphorite and apatite and as so-called pebble deposit and phosphate rock. Phosphorus in some sort of combination is one of the most essential elements in animal and plant food. In animals its compounds form almost all of the mineral matter of the bones, and in plants they are important constituents of the ash of seeds. It exists in organic combination both in animal and vegetable tissues such as lecithines and other compounds.

The mineral deposits of phosphorus, as well as bones, are chiefly tri-calcium phosphate, while the slag compound resulting from the basic treatment of iron ores rich in phosphorus is a tetra-calcium salt.

The pebble deposits and some rock phosphates are supposed to be of organic origin, derived from the remains of marine, terrestrial and aerial animals. The mean content of phosphorus found in 211 samples of volcanic and crystalline rocks is 0.22 per cent.³

12. Nitrogen as a mineral constituent of soils, is found chiefly in the form of nitrates, but, owing to their solubility, they can not accumulate in soils exposed to heavy rainfalls. The gaseous nitrogen in the soil is also of some importance, since it is on this material that the organisms which have a symbiotic activity with the rootlets of some plants probably act in the process of the fixation of atmospheric nitrogen in a form accessible to plants. Nitrogen in the free state, it is believed, is not directly absorbed into the tissues of green plants. It is necessary that it be oxidized in some way to nitric acid or some compound containing it before it can be assimilated. The importance of nitrogen as a plant food can not be too highly estimated. It is as necessary to plant growth and development as water, phosphoric acid, lime and potash, and is far more costly. While a large quantity of nitrogen exists in the air in an uncombined state, it is, nevertheless, one of the least abundant of the available elements of high importance in plant nutrition.

The conservation and increase of the stores of available nitrogen in the soil is one of the chief problems occupying the attention of agricultural chemistry. Nitrogen, which is not immediately available for the growth of plants, is conserved and restored by natural processes in various ways. A further discussion of this subject is found in the second volume of this work.

13. Boron occurs chiefly in volcanic regions, but is much more widely distributed in the soil than formerly believed. It is a constituent of the ash of many plants, and is thought by some to be a true plant food.⁴ A more reasonable theory is that its presence in vegetable products is a mere incident to its occur-

³ Bulletin Philosophical Society of Washington, 11 : 136.

⁴ Crampton : American Chemical Journal, 1890, 2 : 227.

rence in the soil. It is one of the least abundant of the elements, not occurring in sufficient quantity to find a place in the table showing their relative abundance, which is to follow. Boric acid and borax are used to some extent as a preservative, especially in meats and dairy products.

14. **Fluorin** does not occur free in nature, but it exists chiefly in combination with calcium, forming fluorspar, traces of which are found widely distributed. In combination chiefly with lime it occurs in bone, teeth, blood, and the milk of mammals. It is one of the elements which does not combine with oxygen, and it can be isolated only with the greatest difficulty. At most only very small traces of it are found in soils. Fluorid of lime is found, however, in considerable quantities in certain phosphate deposits.

15. **Aluminum** is, probably, next to oxygen and silicon, the most abundant element of the earth's crust, of which it is estimated to form about one-twelfth. It has never been found, in nature, in the free state, but commonly occurs in combination with silicon and oxygen, in which form it is an abundant constituent of feldspar, mica, kaolin, clay, slate, and many other rocks and minerals.

By the weathering of feldspar, mica, and other minerals containing aluminum, true clay is formed, which is of the greatest importance in the constitution of the soil. The compounds of aluminum are not important as plant food except when they contain potash but they form valuable constituents of the soil, furnishing a large part of its bulk, and modifying in the most profound degree its physical properties. It is the custom of some authors to use the word clay to designate the fine particles of soil which have in general the same relations to moisture and tilth as the particles of weathered feldspar, etc. In a strict chemical sense, however, the term clay is applied only to the silicates of alumina and the silica found therewith formed as indicated above. The fertility of a soil is indirectly dependent on the quantity of clay which it contains, its relations to moisture and amenability to culture being largely conditioned by its clay content. The determination of the percentage of clay in soils is an operation of the highest

MAGNESIUM

utility in forming an opinion of the value of a soil based on physical data alone.

16. **Calcium** is one of the commonest and most important elements of the earth's crust, of which it has been estimated to compose about one-sixteenth. It does not occur free in nature, but its most common condition is in combination with carbon dioxide, forming the mineral calcite, and as marble, and the very abundant limestone rocks. In this form it is slightly soluble in water, especially when containing carbon dioxide, and hence lime is very generally found in natural waters, in which it furnishes the chief ingredient necessary for the formation of the shells and skeletons of the various species of mollusca and corals. In combination with sulfuric acid calcium forms the rock gypsum. Lime is not only a necessary plant food, but also influences in a marked degree the physical condition of the soil and the progress of nitrification. Many stiff clay soils are rendered porous and pulverulent by an application of lime, and thus made far more productive. The sourness or acidity of soils is also corrected by the application of lime. Although existing in great abundance it has not commanded the degree of attention from farmers and agricultural chemists which its merits deserve. It forms an essential ingredient of plants and animals, in the latter being collected chiefly in the bones, while in plants it is rather uniformly distributed throughout all the tissues. Both in common language and in chemistry the term lime is applied to the product of burning limestone (carbonate of lime) until the carbon dioxide is expelled. In the freshly burned state lime contains no water. When exposed to the air it gradually absorbs water in chemical combination and becomes slaked lime. This change takes place with great rapidity and with the evolution of much heat on the application of water.

17. **Magnesium** occurs chiefly in combination with silica and carbon dioxide or with lime and carbon dioxide in the mineral dolomite. It is intimately associated with calcium and a trace of it is nearly always found where lime occurs in any considerable quantity. The bitter taste of sea water and some mineral waters is often due to the presence of salts of magnesia. In combination with silica it forms an essential part of such rocks as serpentine,

soapstone, and talc. Magnesia is useful, especially in the formation of seeds, but it is not absent from other parts of the plant. It performs its functions best in the presence of calcium compounds and in the absence of the latter magnesia salts may easily be injurious.

18. **Potassium** combined with silica is an important element in many silicates as, for instance, orthoclase. Granite rocks usually contain considerable quantities of potassium, and on their decomposition this becomes available for plant food. In the form of chlorid, potassium is found in small quantities in sea water, and as a nitrate it forms the valuable salt known as niter or saltpeter. Potassium, as is the case with phosphorus, is universally distributed in soils, and forms one of the great essential elements of plant food. Under the form of kainite and other minerals large quantities of potassium are used for fertilizing and for the manufacture of pure salts for commercial and pharmaceutical purposes. The ordinary potassium salts are very soluble and for this reason they can not accumulate in large quantities in soils exposed to heavy rainfall. In the form of carbonate, potassium forms one of the chief ingredients of hard wood ashes, and in this form of combination is especially valuable for fertilizing purposes. Potash salts, being extremely soluble, are likely to be held long in solution. Some of them are recovered in animal and vegetable life, but the great mass of potash carried into the sea still remains unaccounted for. The recovery of the waste of potash is chiefly secured by the isolation of sea waters containing large quantities of this salt and their subsequent evaporation. Such isolation of sea waters takes place by means of geological changes in the level of the land and sea. In the raising of an area above the water level there is almost certain to be an enclosure, of greater or less extent, of the sea water in the form of a lake. This enclosure may be complete or only partial, the enclosed water area being still in communication with the main body of the sea by means of small estuaries. If this body of water be exposed to rapid evaporation as was doubtless the case in past geological ages, there will be a continual influx of additional sea water through these estuaries to take the place of that evaporated. The waters may thus become more and more charged with saline constituents. Finally a point

is reached in the evaporation when the less soluble of the saline constituents begin to be deposited. In this way the various formations of mineral deposits, produced by the drying up of enclosed waters takes place. The principles of physical chemistry explain the manner in which these saline deposits are laid down.⁶ An account of the deposition of the potash salts near Stassfurt, Germany, is found in Vol. II.

19. Sodium is never found free in nature, but its most common form is in combination with chlorine as common salt, an important ingredient of sea water. Combined with silica sodium is an important element in many silicates. Sodium, although closely related to potassium chemically, cannot in any case be substituted therefor in plant nutrition. While it is certain that plants can thrive without a trace of sodium, it is believed to be helpful in some cases, and its salts may replace those of potassium in so far as osmotic and neutralizing functions are concerned. In combination with nitrogen it forms soda (or Chile) saltpeter which is a valuable fertilizer on account of its content of nitric acid.

20. Iron is the most abundant of the heavy metals, and occurs in nature both free and combined with other elements. In the free state it is found only to a limited extent in basaltic rocks and meteorites, but in combination with oxygen it is one of the most widely diffused of metals, and forms the coloring matter of a large number of rocks and minerals. In this form, too, it exists as the valuable ores of iron known as magnetite and hematite. In combination with sulfur it forms the mineral pyrite, FeS_2 . The yellow and red colors of soils are due chiefly to iron oxides. Iron salts are essential to the production of chlorophyll, and to its functional activity. Iron is one of the essential constituents of the haemoglobin of the blood without which oxygen could not be properly carried to every part of the body.

21. Titanium is apparently of no importance in plant nutrition, but its occurrence in many soils requires recognition in soil analysis. It has been found to be one of the most widely distributed elements.⁶

⁶ Van't Hoff (Chicago University lectures).

⁶ Dunnigton: Proceedings of the American Association for the Advancement of Science, 34 : 132 ; American Journal of Science, 42 : 491 ; American Chemical Journal, 10 : 36 ; Baskerville : Journal American Chemical Society, 21 : 1099.

22. Manganese, next to iron, is the most abundant of the heavy metals. It occurs in nature in combination with oxygen, in which form it is associated in minute quantities with iron in igneous rocks or in the forms known mineralogically as pyrolu^site, psilomelane and wad. As the peroxid of manganese it occurs in concretionary forms scattered abundantly over the bottom of the deep sea. It is found in the ash of some plants, but is not believed to be an essential to plant growth.

23. Chromium in so far as known takes no part in plant nutrition and its occurrence in the soil is only of importance from an analytical and color standpoint.

24. Barium occurs in nature combined with sulfuric acid, forming the mineral barite, or heavy spar, or with carbon dioxid forming the mineral witherite. It is of small importance from an agricultural standpoint.

25. Relative Abundance of the More Important Chemical Elements.—It will be of interest to the agricultural analyst to know as nearly as possible the relative abundance of the more important chemical elements. This subject has been carefully studied by Clarke on data supplied by Woodward.¹ The materials considered in these calculations are the atmosphere, the water, and the solid crust of the earth to the depth of 10 miles below the sea level. Of these materials, assuming the mean density of the earth's crust to the depth of 10 miles to be 2.5, the relative quantities of the three constituents named are as follows:

	Per cent.
Atmosphere	0.03
Water	7.08
Solid crust of the earth to a depth of 10 miles.....	92.89

According to these calculations the relative abundance of the important elements composing the atmosphere, the water of the ocean and the solid crust of the earth to the depth given is as follows:

¹ Bulletin of the Philosophical Society of Washington, 2 : 131 et seq.

	Solid crust, 93 per cent.	Ocean, seven per cent.	Mean, including air.
Oxygen.....	47.29 per cent.	85.79 per cent.	49.98 per cent.
Silicon.....	27.21 " "	.... " "	25.30 " "
Aluminum.....	7.81 " "	... " "	7.26 " "
Iron.....	5.46 " "	.... " "	5.08 " "
Calcium.....	3.77 " "	0.05 " "	3.51 " "
Magnesium.....	2.68 " "	0.14 " "	2.50 " "
Sodium.....	2.36 " "	1.14 " "	2.28 " "
Potassium.....	2.40 " "	0.04 " "	2.23 " "
Hydrogen.....	0.21 " "	10.67 " "	0.94 " "
Titanium.....	0.33 " "	.... " "	0.30 " "
Carbon.....	0.22 " "	0.002 " "	0.21 " "
Chlorin.....	0.01 " "	2.07 " "	} 0.15 " "
Bromin.....	.... " "	0.008 " "	
Phosphorus.....	0.10 " "	1... " "	0.09 " "
Manganese.....	0.08 " "	... " "	0.07 " "
Sulfur.....	0.03 + " "	0.09 " "	0.04 + " "
Barium.....	0.03 " "	.... " "	0.03 " "
Nitrogen.....	.... " "	.... " "	0.02 " "
Chromium.....	0.01 " "	.... " "	0.01 " "
	100.00 " "	100.000 " "	100.00 " "

Nineteen of the more important elements are included in the above table. The aggregate of all the other elements can not be more than one per cent. of the earth's crust, and is probably less than that amount, and no one of them could exceed five-tenths per cent. Most of them occur in such minute quantities as to render any attempt to express them numerically futile.

26. **Fluorin** is not mentioned in this table but it is stated that its probable percentage is two-tenths to three-tenths making it thus slightly more abundant than nitrogen.

One of the points of interest in connection with this table is that nitrogen which is regarded by most persons as one of the most abundant of the elements is almost the least abundant of those mentioned.

THE MINERALS OCCURRING IN ROCKS.

27. **The Soil**, as before stated, being composed almost exclusively of decayed rocks, its characteristics would naturally be determined in great part by the character of the minerals contained in the rocks.

A rock may be composed of a single mineral or an aggregation of several minerals.

According to Merrill, rocks may occur either in the form of stratified beds, eruptive masses, sheets or dikes, or as veins and other chemical deposits of comparatively little importance as regards size and extent.⁸ The mineral composition of rocks is greatly simplified by the wide range of conditions under which the commonest minerals can be formed. Thus quartz, feldspar, mica, and the minerals of the hornblende, or pyroxene group, can be formed from a mass cooling from a state of fusion; they may be crystallized from solution, or be formed from volatilized products. They are therefore the commonest of minerals and are rarely absent in rocks of any class, since there is no process of rock formation from which they are necessarily excluded.

Most of the common minerals, like the feldspars, micas, hornblendes, pyroxenes, and the alkaline carbonates possess the capacity of adapting themselves to a very considerable range of compositions. In the feldspars, for example, lime, soda, or potash may replace one another almost indefinitely, and it is now commonly assumed that true species do not exist, but all are but isomorphous admixtures passing into one another by all gradations, and the names albite, oligoclase, anorthite, etc., are to be used only as indicating convenient stopping and starting points in the series. Hornblende or pyroxene, further, may be pure silicate of lime and magnesia, or iron and manganese may partially replace these substances. Lime carbonate may be pure, or magnesia may replace the lime in many proportions.

These illustrations are sufficient to show the reason for the great simplicity of rock masses as regards their chief mineral constituents.

Whatever may be the conditions of the origin of a rock mass, the probabilities are that it will be formed essentially of one or more of a half a dozen minerals in some of their varieties.

But however great the adaptability of these few minerals may be they are, nevertheless, subject to very definite laws of chemical equivalence. There are elements which they cannot take into their composition, and there are circumstances which retard their

⁸ Handbook Department of Geology, U. S. National Museum, 508, et seq.

formation while other minerals may be crystallizing. In a mass of rock of more or less accidental composition formed under these widely varying conditions it may, therefore, be expected that ~~other~~ minerals will form, in considerable numbers, but minute quantities. It is customary to speak of those minerals which form the chief ingredients of any rock, and which may be regarded as characteristic of any particular variety, as the essential constituents, while those which occur in but small quantities, and whose presence or absence does not fundamentally affect its character, are called accessory constituents. The accessory mineral which predominates, and which is, as a rule, present in such quantities as to be recognizable by the unaided eye, is the characterizing accessory. Thus a biotite granite is a stone composed of the essential minerals quartz and potash feldspar, but in which the accessory mineral biotite occurs in such quantities as to give a definite character to the rock.

28. Classification of Minerals.—The minerals of rocks may also be conveniently divided into two groups, according as they are products of the first consolidation of the mass or of subsequent changes. This is the system here adopted. We thus have:

(1) The original or primary constituents, those which formed upon the first consolidation. All the essential constituents are original, but on the other hand all the original constituents are not essential. Thus, in granite, quartz and orthoclase are both original and essential, while beryl, zircon or apatite, though original, are not essential.

(2) The secondary constituents are those which result from changes in a rock subsequent to its first consolidation, changes which are due in great part to the chemical action of percolating water. Such are the calcite, chalcedony, quartz, and zeolite deposits which form in the druses and amygdaloidal cavities of traps and other rocks.

Below is given a list of the more common, original and secondary minerals occurring in rocks. It will be observed that the same mineral may, in certain cases, occur in both original and secondary forms. The tables following of original and secondary minerals are given by Merrill.⁹

⁹ Rocks and Soils, 11-12; Handbook for Department of Geology, 510.

A. ORIGINAL MINERALS

- | | |
|------------------------------|------------------------------|
| 1. Quartz. | 6. The Micas. |
| 2. The Feldspars. | 6a. Muscovite. |
| 2a. Orthoclase. | 6b. Biotite. |
| 2b. Microcline. | 6c. Phlogopite. |
| 2c. Albite. | 7. Calcite (and Aragonite). |
| 2d. Oligoclase. | 8. Dolomite. |
| 2e. Andesite. | 9. Gypsum. |
| 2f. Labradorite. | 10. Olivine. |
| 2g. Bytownite. | 11. Garnet. |
| 2h. Anorthite. | 12. Epidote. |
| 3. The Amphiboles. | 13. Zoisite. |
| 3a. Hornblende. | 14. Andalusite. |
| 3b. Tremolite. | 15. Staurolite. |
| 3c. Actinolite. | 16. Scapolite. |
| 3d. Arvedsonite. | 17. Elaeolite and Nepheline. |
| 3e. Glaucophanes. | 18. Leucite. |
| 3f. Smaragdite. | 19. Sodalite. |
| 4. The Monoclinic Pyroxenes. | 20. Hauyn (nosean). |
| 4a. Malacolite. | 21. Apatite. |
| 4b. Diallage. | 22. Menaccanite. |
| 4c. Augite. | 23. Magnetite. |
| 4d. Acmite. | 24. Hematite. |
| 4e. Aegerite. | 25. Chromite. |
| 5. The Rhombic Pyroxenes. | 26. Halite (common salt). |
| 5a. Eustatite (Brouzite). | 27. Fluorite. |
| 5b. Hypersthene. | 28. Graphite. |
| | 29. Carbon. |
| | 30. Pyrite. |

B. SECONDARY MINERALS

- | | |
|-----------------------------|-------------------|
| 1. Quartz. | 14. Glauconite. |
| 1a. Chalcedony. | 15. Kaolin. |
| 1b. Opal. | 16. The Zeolites. |
| 1c. Tridymite. | 16a. Pectolite. |
| 2. Albite. | 16b. Laumontite. |
| 3. The Amphiboles. | 16c. Phrenite. |
| 3a. Hornblende. | 16d. Thomsonite. |
| 3b. Tremolite. | 16e. Natrolite. |
| 3c. Actinolite. | 16f. Analcite. |
| 3d. Uralite. | 16g. Datolite. |
| 4. Muscovite (Sericite). | 16h. Chabazite. |
| 5. The Chlorites. | 16i. Stilbite. |
| 5a. Jefferisite. | 16k. Heulandite. |
| 5b. Ripidolite. | 16l. Phillipsite. |
| 5c. Penninite. | 16m. Ptilolite. |
| 5d. Prochlorite. | 16n. Mordenite. |
| 6. Calcite (and Aragonite). | 16o. Harmotome. |
| 7. Wollastonite. | 17. Hematite. |
| 8. Scapolite. | 18. Limonite. |
| 9. Garnet. | 19. Gôthite. |
| 10. Epidote. | 20. Turrite. |
| 11. Zoisite. | 21. Pyrite. |
| 12. Serpentine. | 22. Marcasite. |
| 13. Talc. | |

Of the above named minerals the feldspars, zeolites, calcite and kaolin are of particular interest to agriculture.

ROCKS AND ROCK DECAY.

29. Types of Rocks.—Rocks may be divided in reference to their structure into four types:¹⁰ First, crystalline; second, vitreous; third, colloidal; fourth, fragmental.

Of these classes there may be selected, as types of the first order, granite and crystalline limestone.

The second class is typically represented by obsidian. Rocks of this kind are confined to a volcanic origin.

The third class of rocks is completely amorphous in its structure and is less common than the others. It is found only in rocks of chemical origin. Types of this class are the siliceous sinters, opals, flint nodules, and many serpentines.

Of the fourth class of rocks, sandstone is typical, being comprised wholly of fragments of rocks pre-existing. The particles may be held together either by cohesion or by a cement composed of silica, iron oxids, carbonate of lime or clayey matter.

30. The Microscopical Structure of Rocks.—A great deal more light is thrown upon the nature of rock materials by microscopical study than by their study in bulk. The requisites for a microscopical study of rock are that the material should be cut into extremely thin laminae with parallel sides and polished so as to transmit the light freely. The study of the crystalline structure of the material is then conducted by means of a microscope furnished with polarizing and analyzing appliances. The light before passing through the mineral film may be polarized by a Nicol prism. After passing through the film it is analyzed by a second Nicol prism. In this way the crystalline structure of the rock as affecting polarized light is distinctly brought out. The thickness of the films examined should be from $\frac{1}{500}$ to $\frac{1}{600}$ of an inch.

The method of rock study by thin microscopic sections is one of comparatively recent origin.

The value of the method is based upon the fact that every crystalline mineral has certain definite optical properties. Therefore, when a crystalline mineral is distorted or misshapen so as to be

¹⁰ Merrill: Handbook of Geology, 512.

incapable of identification by the ordinary method, it can be at once identified by its optical examination in the manner just described. In this way not only can one mineral be distinguished from another, but the crystalline system to which it belongs can be accurately pointed out. The value of the method is well summed up by Merrill, who says that it is not merely an aid in determining the mineralogical composition of a rock, but also, which is often much more important, its structure and the various changes which have taken place in it since its first consolidation.¹¹ Rocks are not the definite and unchangeable mineral compounds they were once considered, but are rather ever varying aggregates of minerals which even in themselves undergo structural and chemical changes almost without number.

Another valuable result of such a study is illustrated by the discovery that the structural features of a rock are not dependent alone upon its chemical composition or geological age, but also upon the conditions under which it cooled from the molten magma. Portions of the same rock may vary all the way from a wholly crystalline to a purely vitreous form.

In the road material laboratory of the Bureau of Chemistry the study of microscopic structure of the substances used for surfacing roads leads to results of the highest practical importance.

Some typical microstructures of crystalline rocks are shown in the accompanying plates I-III.¹²

Although this method of study has thus far been confined mainly to crystalline rocks, its efficiency is by no means limited to them. The fragmental rocks and their decomposed debris to which the name soil is given are equally worthy of study by this method. Indeed, the full value of a chemical analysis of any rock or soil can not be ascertained unless such an analysis is accompanied by a microscopic examination. It is desirable to know not merely what there is in any soil, but in what physical form these compounds exist. To this latter question the chemical analysis as ordinarily made will give no clew. An outline of the method of analysis is given in the proper place.

¹¹ Handbook for Department of Geology, 515.

¹² Bulletin No. 79 Bureau of Chemistry, Plates I-IV.



Fig. 1.—Basalt (Trap).

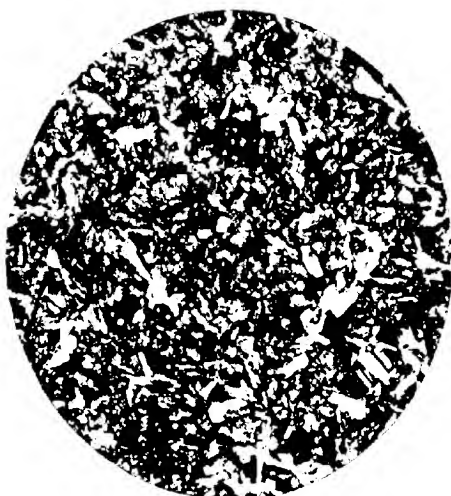


Fig. 2.—Diabase (Trap).

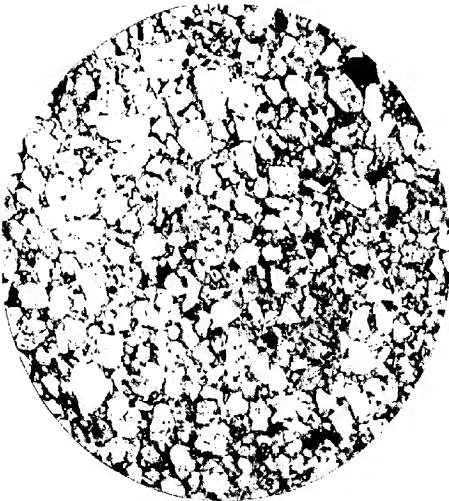


Fig. 3.—Quartzite.



Fig. 4.—Limestone.



Fig. 5.—Gneiss.



Fig. 6.—Granite.

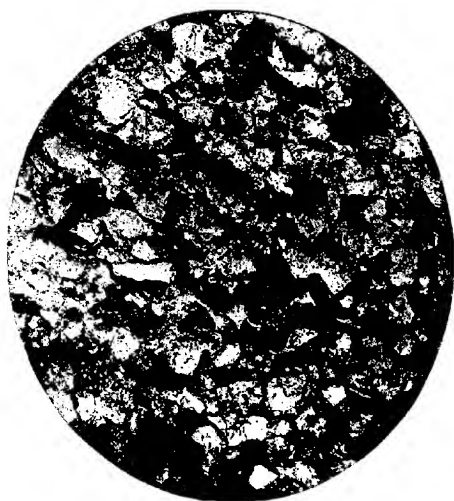


FIG. 7.
Microscopic Structure of Sandstone.

31. Specific Gravity.—Much information in regard to the properties of a rock, or mineral constituent thereof, may be derived from its specific gravity.

The internal structure of a rock may have much to do with its apparent specific gravity. As an instance of this, it may be stated that an obsidian pumice will float upon water, buoyed up by the air contained in its vesicles, while a compact obsidian of the same composition will sink immediately. A careful discrimination must, therefore, be made between apparent and true specific gravity. In general it may be said that crystalline rocks have a higher specific gravity than those of a vitreous nature. The specific gravity is, therefore, largely dependent upon chemical and crystallographic properties; for instance, among siliceous rocks those which contain the largest amount of silica are the lightest, while those with a comparatively small amount, but rich in iron, lime, magnesia and baryta are heaviest.

32. Chemical Classification of Rocks.—Rocks are often classified in respect of the chief mineral constituent which they contain. Rocks which are composed largely of lime are termed calcareous; of silica, siliceous; of iron, ferruginous and of clay, argillaceous. In respect of eruptive rocks, it is customary to speak of those which show above 60 per cent. of silica as acidic, while those containing less than 50 per cent. of silica and a correspondingly larger amount of iron, lime, and magnesia, are spoken of as basic. Illustrations of the classification of rocks on the above principles are given below.¹³

STRATIFIED ROCKS		
Kind.	Specific gravity.	Composition
Calcareous:		
Compact limestone.....	2.6 to 2.8	Carbonate of lime.
Crystalline limestone.....		
Compact dolomite.....	2.8 to 2.95	Carbonate of lime and magnesia.
Crystalline dolomite.....		
Siliceous:		
Gneiss.....	2.6 to 2.7	Same as granite.
Siliceous sandstone.....	2.6	Mainly silica.
Schist.....	2.6 to 2.8	60 to 80 per cent. silica.
Argillaceous:		
Clay slate (argillite).....	2.5	Mainly silicate of alumina.

¹³ Merrill: Handbook of Geology, 521; Rocks and Soils, 45.

ERUPTIVE ROCKS

	Specific gravity.	Per cent. silica.
Acidic Group:		
Granite.....	2.58 to 2.73	77.65 to 62.90
Liparite.....	2.53 to 2.70	76.06 to 67.61
Obsidian.....	2.26 to 2.41	82.80 to 71.19
Obsidian pumice.....	Floats on water	82.80 to 71.19
Intermediate Group:		
Syenite.....	2.73 to 2.86	72.20 to 54.65
Trachyte.....	2.70 to 2.80	64.00 to 60.00
Hyalotrichyte.....	2.4 to 2.5	64.00 to 60.00
Andesite.....	2.54 to 2.79	66.75 to 54.73
Basic Group:		
Diabase.....	2.66 to 2.88	50.00 to 48.00
Basalt.....	2.90 to 3.10	50.59 to 40.74
Peridotite.....	3.22 to 3.29	42.65 to 33.73
Peridotite (iron rich).....	3.86	23.00
Peridotite (meteorite).....	3.51	37.70

33. Color of Rocks.—The color of rocks is determined chiefly by the oxids of metals which they contain and the degree of oxidation of the mineral in each particular case. There are, however, many colors of rocks which seem to depend not upon any particular mineral ingredient, but upon some particular crystalline structure or physical condition.¹⁴

The chief coloring matters in minerals are those which form colored bases such as iron, manganese, chromium, etc. The yellow, brown, and red colors, common to fragmental rocks, are due almost wholly to free oxids of iron. The gray, green, dull brown, and even black colors of crystalline rocks are due to the presence of free iron oxids or to the prevalence of silicate mineral rich in iron, as augite, hornblende, or black mica. Rarely copper and other metallic oxids than those of iron are present in sufficient abundance to impart their characteristic hues. As a rule, a white or light-gray color denotes an absence of an appreciable amount of iron in any of its forms. The bluish and black colors of many rocks, particularly the limestones and shales, are due to the presence of organic matter.

In still other cases, and particularly the feldspar-bearing rocks, the color may be due to the physical condition of the feldspar.

¹⁴ Merrill : Smithsonian Report, 1890 ; Handbook of Geology, 521.

Inasmuch as the color of rocks is due so largely to metallic oxides, it is easy to see that they may undergo changes when exposed to weathering, or the degree of oxidation may change, and either, together with changes in the physical structure of the rock, may cause a distinct change in color. Luster is often considered in connection with color, and is due almost exclusively to physical conditions.

34. Kinds of Rocks.—The rocks which form any essential part of the earth's crust are grouped under four main heads, the distinction being based upon their origin and structure.¹⁵ Each of the main divisions may be subdivided into groups or families, the distinction being based mainly upon chemical composition, structure, and mode of occurrence. The four chief families are:

First, aqueous rocks, formed mainly through the agency of water as chemical precipitates or as sedimentary beds.

Second, aeolian rocks, formed from wind-drifted materials.

Third, metamorphic rocks, changed from their original condition through dynamic or chemical agencies, and which may have been partly of aqueous and partly of igneous origin.

Fourth, igneous or eruptive rocks, which have been brought up from below in a molten condition, and which owe their present structural peculiarities to variations in composition and conditions of solidification.

35. Aqueous Rocks.—Aqueous rocks may be divided into the following general classes:

First, rocks formed as chemical precipitates.

Second, rocks formed as sedimentary deposits and fragmental in structure. The second class may again be subdivided into rocks formed by mechanical agencies and mainly of inorganic materials; and second, rocks composed mainly of the debris of plant and animal life.

In regard to the first form of aqueous rocks, namely, those formed as chemical precipitates, it may be said that while their quantity is not large they are yet of considerable importance from an agricultural point of view. They embrace those substances

¹⁵ Merrill: Smithsonian Report, 1890; Handbook of Geology, 536; Rocks and Soils, 57.

which, having once been in a condition of vapor or aqueous solution, have been deposited or precipitated, either by cooling or by the evaporation of the liquor holding them in solution, or by coming in contact with chemical substances capable of precipitating them. The influence of water as a solvent is perhaps not fully appreciated. Its solvent influence will be noted particularly under the head of weathering or decay of rocks. Its importance, however, in producing stratified rocks has been very great. Water, especially when under great pressure and at a high temperature, has the power of dissolving many minerals. This power is often greatly increased by the mineral matter previously in solution in the water or by the gases which it may contain. As an illustration of the latter property, the solvent action of water charged with carbon dioxid on limestone may be cited.

When mineral matters have been dissolved by the water in the ways mentioned and carried with the water beyond the environment where the solution has taken place, new conditions are found favorable to the precipitation of the dissolved matters. The water, which before may have been very hot, may reach a place where it cools, and being a supersaturated solution, the excess of the material is thrown down.

On the other hand, if the solution be due to the presence of carbon dioxid and the water reach a place where it is exposed to the air or where the pressure to which the absorption of the excess of gas has been due is diminished, the carbon dioxid will escape and the mineral matters which have been dissolved thereby will be precipitated.

The incrustations which often appear around the mouths of springs and the occurrence of stalagmites and stalactites in caves are illustrations of this action.

In respect of the formation of rocks as precipitates from a state of vapor we have scarcely any illustrations excepting in volcanic regions. The rocky materials with which we are generally acquainted are practically non-volatile at the highest temperature which can be secured on the earth's surface, but it is possible that in the interior of the earth the temperature may be so high as to

maintain many substances in a state of vapor, or which would be gases at that high temperature at ordinary pressures.

They may, in this case, become disassociated so that the compounds or elements exist distinctly in a vaporous condition. Such a vapor transported to regions of diminished temperature would first of all on cooling permit a union of the chemical elements forming new compounds less volatile, which, of course, would be at once precipitated.

The rocks and minerals formed possibly in this way which are of some agricultural importance may be classified as follows: Oxids, carbonates, silicates, sulfids, sulfates, phosphates, chlorids, and hydrocarbon compounds, the most important from an agricultural point of view being the phosphates.

The second group of rocks, namely those formed as sedimentary deposits, differ from those just described in that they are comprised mainly of fragmental materials derived from the breaking down of pre-existing rocks. The formation of fragmental rocks includes, therefore, the same processes as are active in the formation of arable soil. They are deposited from water, and are as a rule distinctly stratified.

Through the action of pressure and the heat thereby generated, or simply through the chemical action of percolating solutions, such rocks pass over into the crystalline sedimentary forms known as metamorphic. All metamorphic rocks, however, are not of a sedimentary origin. For instance, by pressure, heat, and the chemical changes thereby induced, granite may be changed into gneiss and the latter would then be a metamorphic rock.

This group of sedimentary rocks and of sedimentary material, either unchanged or metamorphosed, is of vast extent and includes materials of widely varying chemical and mineralogical nature. They form by far the greater portion of the present surface of the earth, even the mountain ranges being composed mainly of this sedimentary material. Indeed, in the whole of this country there is only a comparatively very small extent of igneous or irruptive rocks. The sedimentary rocks are of great importance from a purely scientific, as well as agricultural viewpoint, since they contain the fossil records of past geological ages.

From them it is possible to study the variations in climate and the meteorological conditions in circumstances and periods far remote, and thus form some idea of the process by which the crust of the earth has been modified by natural forces from its original form to the present time.

36. Classification of Sedimentary Rocks.—The sedimentary rocks may be divided, as described by Merrill, with sufficient accuracy for our purposes, into two great classes: First, rocks formed by mechanical agencies and mainly of inorganic materials. These are subdivided again as follows:

- (a) The arenaceous group.
- (b) The argillaceous group.
- (c) The volcanic group.

The second class of sedimentary rocks is formed largely, or in part at least, by mechanical agencies, but is comprised chiefly of the debris of plant and animal life. It may be subdivided as follows:

- (d) The siliceous group, such as infusorial earth.
- (e) The calcareous group, fossiliferous formations, limestone, etc.
- (f) The carbonaceous group, such as peat, lignite, coals, etc.
- (g) Phosphatic deposits.

The different classes of rock described above are distinguished by special qualities represented largely by the name.

(a) The first division, the arenaceous group, is composed mainly of the siliceous or coarsely granular materials derived from the disintegration of older crystalline rocks, which have been rearranged in beds of varying thickness through the mechanical agency of water. They are, in short, consolidated or unconsolidated beds of sand and gravel. In composition and texture they vary almost indefinitely. Many of them having suffered little during the process of disintegration and transportation are composed essentially of the same materials as the rocks from which they were derived.

The sandstones, which are the type of these rocks, vary greatly

in structure as well as in composition, in some the grains being rounded while in others they are sharply angular.

The microscopic structure of sandstone is shown in figure seven.¹⁶

The substance by which the individual grains of a sandstone are bound together is usually the material of some of the other classes, the calcareous, ferruginous, and siliceous cements being the most usual binding agents. This cementing substance is deposited among the granules forming the sandstone by percolating water.

The colors of sandstone are dependent usually upon iron oxids. Especially is this true of the red, brown, and yellow colors. In some of the light grey varieties, the color is that of the minerals comprising the stone. Some of the darker colored sandstones contain organic matter.

(b). The rocks of the argillaceous group are composed essentially of a hydrous silicate of alumina, which is the basis of common clay, and varying amounts of free silica, oxids of iron and manganese, carbonates of lime and magnesia, and small quantities of organic matter. They may have originated *in situ* from the decomposition of feldspars or as deposits of fine mud or silt at the bottom of large bodies of water. The older formations of these rocks are known as shales, argillites and slates and the fissile structure which enables them to be split into thin sheets is probably due to the conditions under which they have been formed and not to any properties of the clay themselves.

One of the purest forms of this rock is kaolin, which is almost a pure hydrous silicate of alumina formed from the decomposition of feldspathic rocks from which the alkalies and other soluble constituents have been removed by water.

(c). Under the volcanic group are included the materials ejected from volcanic vents in a more or less finely comminuted condition and which through the drifting power of atmospheric currents may be scattered over many square miles of territory. Various names are applied to such products, names dependent in

¹⁶ Photomicrograph, Road Material Laboratory, Bureau of Chemistry (Howard & Lord).

large part upon their state of subdivision. Volcanic dust or ashes, includes the finer dust-like or sand-like materials, and lapilli, or rapilli, the coarser. The general name tuff, or tuffa, includes the more or less compacted and stratified beds of this material, while trass, peperino, and pozzuolana are local varietal names given to similar materials occurring in European volcanic regions.¹⁷

The second division, namely sedimentary rocks composed of the débris of plant and animal life includes many forms of great agricultural importance.

(d) The first subdivision of this group is the infusorial or diatomaceous earth. It forms a fine white or yellowish pulverulent rock composed mainly of minute shells, or tests of diatoms, and is often so soft and pliable as to crumble readily between the thumb and fingers. The beds are of comparatively limited extent, and for this reason are of little agricultural value, although the weathering of this diatomaceous material gives rise to a light yellow clay forming very fertile agricultural lands. Diatomaceous earth has many technical uses such as in filtering and as an absorbent for nitroglycerine.

(e) The second subdivision of this group includes the rocks of a calcareous nature derived from animal life; that is to say, what are properly called limestones. They vary in color, structure, and texture almost indefinitely, and include all possible grades of materials from those which can be used only as a flux, or for lime burning, through ordinary building materials to the finest marbles. These rocks are world-wide in their distribution and limited to no one particular geological era, but are found in stratified beds among deposits of all ages from the most ancient to the most recent.

Owing to the fact that their chief constituent, carbonate of lime, is soluble in ordinary meteoric waters, the rocks have undergone extensive decomposition, their lime being removed, while their less soluble constituents or impurities remain to form one of the chief constituents of soil. A single ton of residual soil represents not infrequently the residue of 100 tons of original rock matter. As this mass of lime carbonate is removed by solution

¹⁷ Merrill: *Rocks and Soils*, 140.

the residual soil settles, and as the limestone rocks are more soluble than the adjacent rock formations limestone formations usually form valley lands with ridges on either side. Caves are frequently found in such formations. Furthermore, as the lime is almost all in the form of the easily soluble lime carbonate it can be very completely removed and the fertile "limestone soils" are often very deficient in lime and respond readily to an application of burnt lime, which, not infrequently, is quarried from the same field. From an agricultural standpoint this group is of very great interest and importance. The celebrated blue grass soils of Kentucky have been formed in the above manner and geologists are of the opinion that by progressive solution of the limestone the surface of the earth in that locality is now far below the position it originally held.

(f) The third subdivision of this group, namely, that of vegetable origin, includes peat, lignite, coals, etc. Rocks of this group are made up of more or less fragmental remains of plants. In many of them, as the peats and lignites, the traces of plant structure are still apparent. In others, as the anthracite coals, these structures have been wholly obliterated by metamorphic changes.

Plants when decomposing on the surface of the ground give off their carbon to the atmosphere in the shape of carbon dioxide gas leaving only the strictly inorganic or mineral matter behind. When, however, they are protected from oxidizing influences by water or by other plant growth, decomposition is greatly retarded, and a large portion of the carbonaceous and volatile matters is retained, and under pressure from the overlying mass, the material becomes slowly converted into coal. When this process goes on near the surface of the earth, and without much pressure, peat is the product.

(g) The fourth subdivision of this group, the phosphatic, forms a class of rocks limited in extent but of the greatest economic importance. Guano, coprolites, and phosphatic rocks (the phosphorites) come under this head.

37. Aeolian Rocks.—This class of rocks is of less importance than the others, either geologically or agriculturally. It is formed

from materials drifted by the winds and this material has various degrees of compactness. Usually the components of these drifts form rocks or deposits of a friable texture and of a fragmental nature. The very extensive deposits of loess in China, forming the most fertile lands, are admitted to have been formed in this way, but it is now generally conceded that similar deposits in this country are of subaqueous origin.

Chief among these rocks, are the volcanic ashes which are often carried to a long distance by the wind before they are deposited and consolidated into rock masses. Many loose soils may be carried to great distances by the wind, the deposits forming new aggregates. This is particularly the case in arid sandy regions.

38. Metamorphic Rocks.—This class of rocks includes all sedimentary or eruptive rocks, which, after their deposition and agglomeration, have been changed in their nature through the action of heat, pressure, or by chemical means. Sometimes these changes are so complete that no indication of the character of the original rocks remains. At other times the changes may be found in all the stages of progress, so that they can be traced from the original fragmental or eruptive to the completely metamorphosed deposit. This is especially true of rocks containing large quantities of lime. In those containing silica, the changes are less readily traced.

The metamorphic rocks may be divided into two subclasses, namely, stratified or bedded, and foliated or schistose.

The rocks of the first class are represented by the crystalline limestones and dolomites. The microstructure of a crystalline limestone is shown in Fig. 4, Plate II. When lime and magnesia occur together in combination with carbon dioxide, the substance is known as dolomite. The chemical nature of these rocks and their soil-forming properties are the same as those of the ordinary, non-metamorphosed limestones and dolomites to which reference has already been made. The subject need not, therefore, be further dwelt upon here.

The second variety of metamorphic rocks is represented by the gneisses and crystalline schists. Gneiss has essentially the same

composition of granite and sometimes can hardly be distinguished from it, except by a microscopic study of its sections, and even then it is sometimes difficult to determine. Frequently a number of new minerals is formed in the metamorphic changes. The microstructure of a gneiss and granite is shown in Figs. 5 and 6. The schists include an extremely variable class of rocks, of which quartz is the prevailing constituent, and which, as a rule, are deficient in potash and other important ingredients of plant food.

39. Rocks Formed Through Igneous Agencies, or Eruptive Rocks.—This group includes all those rocks, which, having been at some time in a state of igneous fusion, have been solidified into their present form by a process of cooling. It may be stated, as a general principle, that the greater the pressure under which a rock solidifies and the slower and more gradual the cooling the more perfect will be found the crystalline structure. Hence, it follows that the older and more deep-seated rocks which are forced up in the form of dikes, bosses, or intrusive sheets, into the overlying masses, and which have become exposed only through erosion and removal of the overlying rocks, are the more highly crystalline.

The eruptive rocks are divided into two main groups, *viz.*:

- (a) Intrusive or plutonic rocks, and
- (b) Effusive or volcanic rocks.

Among the more important of the first division of the plutonic form, from an agricultural point of view, are the granites. The essential constituents of granite are quartz, potash feldspar, and plagioclase. One or more minerals of the mica, amphibole or pyroxene groups are also commonly present, and in microscopic proportions apatite and particles of magnetic iron. The more valuable constituents, from an agricultural standpoint, are the minerals potash feldspar, and apatite, which furnish by their decomposition potash and phosphoric acid.

In addition to the granites, which have already been mentioned, the group includes the syenites, the nepheline syenites, the diorites, the gabbros, the diabases, the theralites, the peridotites, and the pyroxenites.

The second group, the effusive or volcanic rocks, includes those igneous rocks, which, like the first group, have been forced up through the overlying rocks, but which were brought to the surface, flowing out as lavas. These, therefore, represent, in many cases, only the upper or surface portions of the first group, differing from them structurally, because they have cooled under little pressure and more rapidly, and hence are not so distinctly crystalline. These rocks according to age, are divided into two groups, the corresponding members of which are given below.¹⁸

EFFUSIVE OR VOLCANIC ROCKS

<i>Paleovolcanic.</i>	<i>Neovolcanic.</i>
Quartz porphyries.	Liparites.
Quartz free porphyries.	Trachytes.
Phonolites.	Phonolites.
Porphyrites.	Andesites.
Melaphyrs and augite porphyrites.	Basalts.
Picrite porphyrites.	Limburgites.

It is, in most cases, impossible to state which of the above classes is of most importance from an agricultural standpoint, since, in the process of soil formation, both chemical and physical processes are involved, whereby the character of the resultant soil is so modified as to but remotely resemble its parent rock. Many soils of volcanic origin are highly fertile and also basic rather than acidic in their constitution.¹⁹ In most soils, the prevailing constituent is the least soluble one of the rock mass from which it was derived. Thus a limestone soil may contain upwards of 90 per cent. of silica and alumina, while the original limestone itself may not have carried more than one or two per cent. of these substances. Of course, if a rock mass contains none of the constituents essential to plant growth, its resultant soil must by itself alone be quite barren. It does not absolutely follow, however, that those rocks containing the highest percentages of valuable constituents will yield the most fertile soils, since much depends on the manner in which they have been formed, and the amount of leaching to which they may have been exposed. Nevertheless, the study of the composition of the rocks in their

¹⁸ Merrill: Rocks and Soils, 63.

¹⁹ Maxwell: Lavas and Soils of the Hawaiian Islands, 61.

relations to soils, is an extremely interesting and by no means unfruitful one.

40. Chemical Composition of Rocks.—The more important elements occurring in rocks and the proportions in which they exist are given in the table below:²⁰

	A.	B.	C.	D.	E.	F.	G.
SiO ₂	55.43	60.15	58.38	78.66	84.86	5.19	14.09
TiO ₂.....	.46	.76	.65	.25	.41	.06	.08
Al ₂ O ₃	13.84	16.45	15.47	4.78	5.96	.81	1.75
Fe ₂ O ₃	4.00	4.04	4.03	1.08	1.39	.54	.77
FeO.....	1.74	2.90	2.46	.30	.84	undet.	undet.
MnO.....	trace	trace	trace	trace	trace	.05	.03
CaO.....	5.96	1.41	3.12	5.52	1.05	42.61	40.60
SrO.....	none	none	none	trace	none	none	none
BaO.....	.06	.04	.05	.05	.01	none	none
MgO.....	2.67	2.32	2.45	1.17	.52	7.90	4.49
K ₂ O.....	2.67	3.60	3.25	1.32	1.16	.33	.58
Na ₂ O.....	1.80	1.01	1.31	.45	.76	.05	.62
Li ₂ O.....	trace	trace	trace	trace	trace	trace	trace
H ₂ O at 110°.....	2.11	.89	1.34	.31	.27	.21	.30
H ₂ O above 110°.....	3.45	3.82	3.68	1.33 ^a	1.47 ^a	.56 ^a	.88 ^a
P ₂ O ₅.....	.20	.15	.17	.08	.06	.04	.42
CO ₂	4.62	1.46	2.64	5.04	1.01	41.58	35.58
S.....	.....	.....	.....	.....	.....	.09	.07
SO ₂.....	.78	.58	.65	.07	.09	.05	.07
Cl.....	.....	.....	.....	trace	trace	.02	.01
Carbon <i>b</i>.....	.69	.88	.81	.....	.....	.....	.....
	100.48	100.46	100.46	100.41	99.86	100.09	100.34

^a Includes organic matter.

^b Of organic origin.

The character of the rocks and the number of analyses from which the mean composition has been calculated are as follows:

A. Composite analysis of 27 Mesozoic and Cenozoic shales. Each individual shale was taken in amount roughly proportional to the mass of the formation which it represented.

B. Composite analysis of 51 Paleozoic shales, weighted as in the former case.

C. General average of A and B, giving them, respectively, weights as 3 to 5. This average represents 78 rocks.

D. Composite analysis of 253 sandstones, about 1 gram of each entering into the average sample.

²⁰ Clarke: Bulletin No. 228 U. S. Geological Survey, 1904, 20-21.

E. Composite analysis of 371 sandstones used for building purposes, equal weights of each.

F. Composite analysis of 345 limestones, equal weights of each.

G. Composite analysis of 498 limestones used for building purposes, equal weights of each.

GENESIS OF SOILS.

41. Origin of Soils.—The soils in which crops grow and which form the subject of the analytical processes to be hereinafter described have been formed under the combined influences of rock decay and plant and other organic growth. The mineral matters of soils have had their origin in the decay of rocks, while the humic and other organic constituents have been derived from living bodies. It is not the object of this treatise to discuss in detail the processes of soil formation, but only to give such general outlines as may bear particularly on the proper conceptions of the principles of soil investigation.

42. The Decay of Rocks.—The origin and composition of rocks are fully set forth in works on geology and mineralogy. Only a brief summary of those points of interest to agriculture has been given in the preceding pages. The soil analyst should be acquainted with these principles, but for practical purposes he has only to understand the chief factors active in securing the decay of rocks and in preparing the *débris* thereof for plant growth.

The following outline is based on the generally accepted theories respecting the formation of soils.

The forces ordinarily concerned in the decay of rocks are:

1. Changes of temperature, including the ordinary daily and monthly changes, and the conditions of freezing and thawing.
2. Moving air, water and ice.
3. Chemical action of water and air.
4. Influence of vegetable life:
 - (a) Shading the rock or soil surface;
 - (b) Penetrating the rock or partly decomposed material with its roots, thus admitting air;

- (c) Solvent action of roots ;
- (d) Chemical action of decaying organic matter.

5. Earth worms.

6. Bacteria.

43. The Action of Freezing and Thawing.—In those parts of a rock stratum exposed near the surface of the earth the processes of freezing and thawing have perhaps had considerable influence in rock decay. The expansive force of freezing water is well known. Ice occupies a larger volume than the water from which it is formed. The force with which this expansion takes place is almost irresistible. The phenomenon of split water pipes which have been exposed to a freezing temperature is not an uncommon one. While the increase in volume is not large, yet it is entirely sufficient to produce serious results. The way in which freezing affects exposed rock is easily understood. The effect is unnoticeable if the rock be dry. If, on the other hand, it be saturated with water, the disintegrating effect of a freeze must be of considerable magnitude. This effect becomes more pronounced if the intervals of freezing and thawing be of short duration. The whole affected portion of the rock may thus become thoroughly decayed. But even in the most favorable conditions this form of disintegration must be confined to a thin superficial area. Even in very cold climates where agricultural pursuits are possible the frost only penetrates a few feet below the surface, and therefore the action of ice cannot in any way be connected with those changes at considerable depths, to which the superficial cover of the earth is obnoxious. Nevertheless, certain building materials seem very sensitive to this sort of weathering, and the crumbling of many building stones is due chiefly to this cause.

On the whole it appears that the action of ice in producing rock decay has been somewhat overrated, although its power must not by any means be denied. But on the other hand a freeze extending over a long time tends to preserve the rocks, and it therefore appears that the entire absence of frost would promote the process of rock decay. If this be true, other things being equal, the decay of the earth's surface would extend to greater depths in

equatorial than in polar regions. Many observed facts tend to corroborate this theory.

At best it must be admitted that frost has affected the earth's crust only to an insignificant depth, but its influence in modifying the arable part of the soil in temperate climate is of great importance to agriculture.

44. The Action of Glaciers.—The action of ice in soil formation is not confined alone to the processes just described. At a period not very remote geologically, a great part of our Northern States was covered with a vast field of moving ice. These seas of ice crept down upon us from more northern latitudes and swept before them every vestige of animal and vegetable life. In their movement they leveled and destroyed the crests of hills and filled the valleys with the débris. They crushed and comminuted the strata of rocks which opposed their flow and carried huge boulders of granite hundred of miles from their homes. On melting they left vast moraines of rocks and pebbles which will mark for all time the termini of these empires of ice. When the ice of these vast glaciers finally melted, the surface which they had leveled presented the appearance of an extended plain. No estimate can be made of the enormous quantities of rock material which were ground to finest powder by these glaciers. This rock powder forms to-day no inconsiderable part of those fertile soils which are composed of glacial drift. The rich materials of these soils probably bear a more intimate relation to the rocks from which they were formed than of any other kinds of soil in the world. The rocks were literally ground into a fine powder, and this powder was intimately mixed with the soils which had already been formed *in situ*. The melting ice also left exposed to disintegrating forces large surfaces of unprotected rocks in which decay could go on much more rapidly than when covered with the débris which protected them before the advent of the ice. The area of glacial action extended over nearly all of New England and over the whole area of the northern central tier of States. It extended southward almost to the Ohio river, and in some places crossed it. The effect of the ice age in producing and modifying our soil must never be forgotten in a study of soil genesis. It is not a part

of our purpose here to study the causes which produced the age of ice. Even a brief reference to some of the more probable ones might be entirely out of place. Before the glacial period it is certain that a tropical climate extended almost, if not quite, to the North Pole. The fossil remains of tropical plants and animals which have been found in high northern latitudes are abundant proofs of this fact.

In the opinion of Sterry Hunt rock decay has taken place largely in preglacial and pretertiary times.²¹ The decay of crystalline rocks is a process of great antiquity. It is also a universal phenomenon. The fact that the rocks of the southern part of this country seem to be covered with a deeper *débris* than those further north may be due in part to the mechanical translation of the eroded particles towards the south. The decay and softening of the material were processes necessarily preceding the erosion by aqueous and glacial action.

It is possible also that a climate may have existed in the earlier geological ages more favorable to the decay of rocks than that of present time.

45. Progress of Decay as Affected by Latitude.—Extensive investigations carried on along the Atlantic side of the country show wide differences in the rate of decay in the same kind of rocks in different latitudes. In general, the progress of decay is more marked toward the south. The same fact is observed in the great interior valleys of the country; at least, everywhere except in the arid and semi-arid regions. Wherever there is a deficiency of water the processes of decay have been arrested. Where the rock strata have been displaced from a horizontal position the progress of decay has been more rapid. This is easily understood. The percolation of water is more easy as the displacement approaches a vertical position.

A most remarkable example of this is seen in the rocks of North Carolina.²² A kind of rock known as trap is found in layers called dikes in the Newark system of rocks in that State. These dikes have been so completely displaced from the horizon-

²¹ *Mineral Physiology and Physiography*, 251.

²² Bulletin No. 52 U. S. Geological Survey, 16.

tal position they at first occupied as to have an almost vertical dip. The edges thus exposed vary from a few feet to nearly 100 feet in thickness. The trap rock in those localities is composed almost exclusively of the mineral dolerite, which is so hard and elastic in a fresh state as to ring like a piece of metal when struck with a hammer. In building a railroad through this region these dikes were in some places uncovered to a depth of forty feet and more. At this depth they were found completely decomposed and with no indications of having reached the lower limit of disintegration. The original hard bluish dolerite has been transformed into a yellowish clay-like mass that can be molded in the fingers and cut like putty. Similar geological formations in New Jersey and further North do not exhibit anything like so great a degree of decomposition, thus illustrating in a marked degree the fact that freezing weather for a part of the year is a protection against rock decay. The ice of winter at least protects the rocks from surface infiltration, although it can not stop the subterranean solution which must go on continuously.

Other things being equal, therefore, it appears that as the region of winter frost is passed the decay of the rocks has been more rapid, because water, the chief disintegrating force, acts more constantly.

46. The Solvent Action of Water.—The water of springs and wells is not pure. It contains in solution mineral matters and often a trace of organic matter. The organic matter comes from contact with vegetable matter and other organic materials near the surface of the earth. The mineral matter is derived from the solvent action of the water and its contents on the soil and rocks.

The expression "hard" or "soft" applied to water indicates that it has much or little carbonate of lime and magnesia or sulfates of the same bases in solution. Water containing much carbonate of lime (or lime and magnesia) in solution is usually more or less charged with carbon dioxid. When boiled this gas is driven off and the carbonates precipitated. This kind of hardness is called temporary. When surface and spring waters are collected into streams and rivers they still contain in solution the greater part of the mineral matters which they at first carried.



Fig. 8.

View West of Chevy Chase, Maryland.

The fresh granite rock is shown passing upward into material more and more decomposed until it becomes sufficiently pulverized and soluble to support plant life. The roots showing in the upper part of the picture formerly penetrated the decomposed rock, but have been exposed through grading operations.

Photograph by E. E. Ewell, 1895.

When waters have more than 600 parts of mineral matter per million they are not deemed suitable for drinking waters. Mineral waters, so called, are those which carry large quantities of mineral matter, or which contain certain comparatively rare mineral substances which are valued for their medicinal effects.

The analysis of spring, well, or river waters will always give some indication of the character of the rocks and soils over or through which they have passed. The vast quantities of mineral matters carried into oceans and seas are gradually deposited as the water is evaporated. If, however, these matters be very soluble, such as common salt, sulfate of magnesia, etc., they are found in concentrated solutions as is seen in sea waters. In small bodies of waters, such as inland seas, which have no outlet, this concentration may proceed to a much greater extent than in the ocean. As an instance of this, it may be noted that the waters of the Dead Sea and Great Salt Lake are impregnated to a far greater degree with soluble salts than the water of the ocean. The solvent action of water on rocks is greatly increased by the traces of organic (or carbonic) acids which it may contain. When surface water comes in contact with vegetable matter it may become partially charged with the organic acids which the growing vegetables may contain or decaying vegetable matter produce. Such acids coming in contact with limestone under pressure will set free carbon dioxid. Water charged with carbon dioxid acts vigorously as a solvent on limestone and some other mineral aggregates. If such waters penetrate deeply below the surface of the earth their activity as solvents may be greatly increased by the higher temperature to which they are subjected. Hence, all these forces combine to disintegrate the rocks, and through such agencies vast deposits of original and secondary rocks have been completely decomposed. The decay of nitrogenous matters gives rise to nitric acid which also adds to the disintegrating power of percolating waters. The gradual passing of the firm rock into an arable soil is beautifully shown in Fig. 8.

Hilgard has called attention to the fact that soils formed with a small supply of water as in the arid regions have a distinctive sandy character, while those formed under the

influence of an abundant supply of water contain more clay.²³ In the decay of rocks therefore a dry climate has a distinctly retarding effect on the kaolinization of feldspathic rocks. The soils formed *in situ* on the Atlantic border are therefore chiefly clay, loams, while on the Pacific border they contain a larger quantity of sand.

47. Action of Vegetable Life.—The preliminary condition to the growth of vegetation is the formation of soil, but once started, vegetation aids greatly in the decomposition of rocks. Some forms of vegetation, as the lichens, have apparently the faculty of growing on the bare surface of rocks, but the higher orders of plants require at least a little soil. Vegetation acts as a rock disintegrant by shading the surface and thus rendering the action of water more effective, by mechanically separating the rock particles by means of its penetrating roots and by the positive action of the root juices. The rootlets of plants in contact with limestone or marble dissolve large portions of these substances, and while their action on more refractory rocks is slower, it must be of considerable importance. It is evident that the solvent action of the acids of living plants is confined almost exclusively to the particles of rocks proximate to points of exudation. The organic matter introduced into the soil by vegetation also promotes decay still further both directly and by the formation of acids of the humic series. This matter also furnishes a considerable portion of carbon dioxide which is carried by the water and assists in its solvent action.

48. Action of Earth-Worms.—Of animal organisms those most active in the formation of soil are earth-worms. The work of earth-worms in soil forming has been exhaustively studied by Darwin.²⁴ The worms not only modify the soil by bringing to the surface portions of the subsoil, but also influence its physical state by making it more porous and pulverulent. According to Darwin the intestinal content of worms has an acid reaction, and this has an effect on those portions of the soil passing through their alimentary

²³ Report California Agricultural Experiment Station, 1892, 107.

²⁴ The Formation of Vegetable Mold through the Action of Worms.

canal. The acids, which are formed in the upper part of the digestive canal are neutralized by the carbonate of lime secreted by the calciferous glands of the worms thus neutralizing the free acid and changing the reaction to alkaline in the lower part of the canal.

The worms further modify the composition of the soil by drawing leaves and other organic matter into their holes, and leaving therein a portion of such matter which is gradually converted into humus. A striking illustration of this process is found in an experiment by von Hensen.²⁵ Darwin estimates that about 11 tons of organic matter per acre are annually added to the soil in regions where worms abound. A considerable portion of the ammonia in the soil at any given time may also be due to the action of worms, as much as 0.18 per cent. of this substance having been found in their excrement. It is probable that nearly the whole of the vegetable matter in the soil passes sooner or later through the alimentary canals of these ceaseless soil builders, and is converted into the form of humus. Finally the bodies of the worms serve to increase the quantity of the organic matter in the soil.

49. Action of Bacteria.—The intimate relations which have been found to subsist between certain minute organisms and the chemical reactions which take place in the soil is a sufficient excuse for noting the effect of other similar organisms in the formation of soils.

In addition to the usual forces active in decomposing rocks Müntz has described the effects of a nitrifying bacillus contributing to the same purpose.²⁶

According to him the bare rock usually furnishes a purely mineral environment where organisms cannot be developed unless they are able to draw their nourishment directly from the air. Some nitrifying organisms belong to this class. It has been shown that these bodies can be developed by absorbing from the ambient atmosphere carbonate of ammonia and vapors of alcohol, the presence of which has been observed in the air. According to the observations of Winogradsky, they assimilate even

²⁵ Stockbridge: *Rocks and Soils*, 131.

²⁶ *Comptes rendus*, 110 : 1370.

the carbon of the carbon dioxide just as the parts of plants which contain chlorophyll. Thus even on the denuded rocks of high mountains the conditions for the development of all these inferior organisms exist. In examining the particles produced by attrition, it is easily established that they are uniformly covered by a layer of organic matter evidently formed by microscopic vegetation. Thus we see, in the very first products of attrition, appearing upon the rocky particles the characteristic element of vegetable soil, *viz.*, humus, the proportion of which increases rapidly with the products of disintegration collected at the foot of declivities until finally they become covered with chlorophylliferous plants.

In a similar manner the presence of nitrifying organisms has been noted upon rocky particles from high attitudes received in sterilized tubes, and where these are sown in an appropriate environment they soon produce colonies. The naked rocks of the Alps, the Pyrenees, the Auvergnés and the Vosges, comprise mineralogical types of the most varied nature, *viz.*, granite, porphyry, gneiss, mica-schist, volcanic rocks and limestones and all these have shown themselves to be covered with the nitrifying ferment. It is known that below a certain temperature these organisms are not active; their action upon the rock is, therefore, limited to the summer period. During the cold season their life is suspended but they do not perish, inasmuch as they have been found living and ready to resume all their activity after an indefinite sleep on the ice of the glaciers where the temperature is never elevated above zero.

The nitrifying ferment is exercised on a much larger scale in the normal conditions of the lower levels where the rock is covered with earth. This activity is not limited to the mass of rock but is continued upon the fragments of the most diverse size scattered through the soil and it helps to gradually reduce them to a state of fine particles. The action of these ferments is therefore a phenomenon of the widest extension.

The action of these micro-organisms according to Müntz is not confined to the surface but extends to the most interior particles of the rocky mass. Where, however, there is nothing of

a nitrogenous nature to nitrify such an organism must live in a state of suspended animation unless it is able to act on the nitrogen of the air.

▪ When the extreme minuteness of these phenomena is considered there may be a tendency to despise their importance, but their continuity and their generality in the opinion of Müntz place them among the geological causes to which the crust of the earth owes a part of its actual physiognomy and which particularly have contributed to the formation of the deposits of the comminuted elements constituting arable soil.

The general action of nitrifying organisms in the soil, the nature of these bodies, and the method of isolating and identifying them will be fully discussed in another part of this work. Brauner calls attention to the danger of overestimating the activity of nitrifying organism in effecting the decay of rocks due to their inability to live at great depths.²⁷ As is well known they diminish in abundance as the depth below the surface increases and disappear, or at least are inactive at depths of from three to six feet. Brauner says that in these cases the statements of specialists are the only safe reliance and the finding of bacteria in rocks by any one not a specialist is to be regarded with suspicion. Only those who have worked in bacteriology can fully appreciate the difficulties to be enumerated and the precautions to be taken in dealing with those organisms in order to prevent being misled by faulty manipulation.

50. Action of the Air.—The air itself takes an active part in rock decay. Wherever rocks are exposed to decay, there air is found or, at least, the active principle of air, *viz.*, oxygen. The air as a gas not only penetrates to a great depth in the earth, but is also carried to much greater depths by water which always holds a greater or less quantity of air in solution. The oxygen of the air is thus brought into intimate contact with the disintegrating materials and is present in a condition to assist wherever possible in the decomposing processes.

The oxygen acts vigorously on the lower oxids of iron, converting them into peroxids, and thus tends to produce decay.

²⁷ American Journal of Science, [4], 3 : 438.

There are other constituents of rocks which oxygen attacks and thus helps to their final breaking up. It is true that, as a rule, the constituents of rocks are already oxidized to nearly as high a degree as possible, and on these constituents of course the air would have no effect. But on others, especially when helped by water with the other substances it carries in solution, the air may greatly aid in the work of destruction.

In a general view, the action of the air in soil formation may be regarded as of secondary importance, and to depend chiefly on the oxidation of the lower to the higher basic forms. These processes, while they seem of little value, have, nevertheless, been of considerable importance in the production of that residue of rock disintegration which constitutes the soil.

51. Classification of Soil According to Deposition.—In regard to their method of deposition soils are divided into five classes:

1. Those which are formed from the decomposition of crystalline or sedimentary rocks or of unconsolidated sedimentary material *in situ*.
2. Those which have been moved by water from the place of their original formation and deposited by subsidence (bottom lands, alluvial soils, lacustrine deposits, etc.).
3. Those which have been deposited as *débris* from moving masses of ice (glacial drift).
4. Soils formed from volcanic ashes or from materials moved by the wind and deposited in low places or in hills or ridges.
5. Those formed chiefly from the decay of vegetable matter, (tule, peat, etc.).

52. Qualities of Soils.—In respect of quality, soils have been arbitrarily divided into many kinds. Some of the more important of these divisions are as follows:

1. *Sand*. Soils consisting almost exclusively of sand.
2. *Sandy Loams*. Soils containing some humus and clay but an excess of sand.
3. *Loams*. Soils inclining neither to sand nor clay and contain-

ing considerable portions of vegetable mold, being very pulverulent and easily broken up into loose and porous masses.

4. *Clays*. Stiff soils in which the silicate of alumina and other fine mineral particles are present in large quantity.

5. *Marls*. Deposits containing an unusual proportion of carbonate of lime, with often some potash or phosphoric acid derived from the remains of sea-animals and plants. It is generally supposed that marls are mixtures more or less intimate of calcium carbonate and clay.²⁸ In general a clay is a definite mixture of silica with hydrous aluminum silicate having a composition $2\text{SiO}_2, \text{Al}_2\text{O}_3 + \text{H}_2\text{O}$. This compound is characterized by the temperature at which it suffers dehydration, viz., about 600° and a marked disengagement of heat which takes place at about 950° . The residue obtained by dissolving a marl in acetic acid never presents the characteristic properties of a typical clay. It is richer in silica and its temperature of dehydration is far inferior. Moreover it does not give any sudden disengagement of heat at elevated temperatures. It is sometimes amorphous, sometimes crystallized, but in this case its crystalline structure is quite different from that of clay particles.

6. *Alkaline*. Soils containing carbonate and sulfate of soda, or an excess of these alkaline and other soluble mineral substances.

7. *Adobe*. A fine grained porous earth of peculiar properties hereinafter described.

8. *Vegetable*. Soils containing much vegetable debris in an advanced state of decomposition. When such matter predominates or exists in large proportion in a soil the term tulle or peat is applied to it.

With the exception of numbers six, seven and eight these types of soil are so well-known as to require no further description for analytical purposes. The alkaline, adobe and vegetable soils on the contrary demand further study.

53. *Alkaline Soils*.—The importance of a more extended notice of this class of soils for analytical purposes is emphasized by their large extent in the United States.

²⁸ Le Chatelier: Comptes rendus, 1894, 118 : 262.

Chiefly through the researches of Hilgard attention has been called to the true character of these soils which are found throughout a large part of the Western United States and which are known by the common name of alkali.²⁹ The following description of the origin of these soils is compiled chiefly from Hilgard's papers on this subject. Wherever the rain-fall is scanty, and especially where the rains do not come at any one time with sufficient force to thoroughly saturate the soil and carry down through the subsoil and off through the drainage waters the alkali contained therein, favorable conditions exist for the production of the alkaline soil mentioned above. The peculiar characteristic of this soil is the efflorescence which occurs upon its surface and which is due to the raising of soluble salts in the soil by the water rising through capillary attraction and evaporating from the surface, leaving the salts as an efflorescence.

Soils which contain a large amount of alkali are usually very rich in mineral plant food, and if the excess of soluble salts could be removed, these lands under favorable conditions of moisture and temperature would produce large crops.

The formation of the alkali may be briefly described as follows: By the decomposition of the native rocks, certain salts soluble in water are formed. These salts in the present matter are chiefly sodium and potassium sulfates, chlorids and carbonates. The salts of potash together with those of lime are more tenaciously held by the soil than the soluble salts of soda, and the result of this natural affinity of the soil for soluble potash, lime and magnesian salts is seen in the formation at the surface of the earth, by the process of evaporation above described, of a crust of alkaline material which is chiefly composed of the soluble salts of soda. In countries which have a sufficient amount of rain-fall, these soluble salts are carried away either by the surface drainage or by the percolation of water through the soil, and the sodium chlorid is accumulated in this way in the waters of the ocean. But where a sufficient amount of rain-fall does not occur, these soluble

²⁹ Bulletins California Agricultural Experiment Station Nos. 28, 53, 83, 105, 108, 121, 133, 140; Annual Reports of Station: 1885, 27; 1890, 87; 1892, 140; 1897, 8; 1898, 21; 1901, 37.

salts carried down by each shower only to a certain depth rise again on the evaporation of the water, reinforced by any additional soluble material which may be found in the soil itself. The three most important ingredients of the alkali of the lands referred to are sodium chlorid, sulfate, and carbonate. When the latter salt, namely, sodium carbonate, is present in predominant quantity, it gives rise to what is popularly known as black alkali. This black color is due to the dark colored solution which sodium carbonate makes with the organic matters or humus of the soil. The black alkali is far more injurious to growing vegetation than the white alkali composed chiefly of sodium sulfate and chlorid.

This black alkali has been very successfully treated by Hilgard by the application of gypsum which reacting with the sodium carbonate produces calcium carbonate and sodium sulfate, thus converting the black into the white alkali and adding an ingredient in the shape of lime carbonate to stiff soils which tends to make them more pulverulent and easy of tillage.³⁰

This method of treatment, however, as can be easily seen, is only palliative, the whole amount of the alkaline substances being still left in the soil, only in a less injurious form.

The only perfect remedy for alkaline soils, as has been pointed out by Hilgard, is in the introduction of underdrainage in connection with irrigation. The partial irrigation of alkaline soils, affording enough moisture to carry the alkali down to and perhaps partially through the subsoil, can produce only a temporary alleviation of the difficulties produced by the alkali. Subsequent evaporation may indeed increase the amount of surface incrustation. For this reason in many cases the practice of irrigation without underdrainage may completely ruin an otherwise fertile soil by slowly increasing the amount of alkali therein by the total amount of the alkaline material added in the waters of irrigation and brought to the surface by the evaporation of the temporarily deeper percolation of the water.

As Hilgard has pointed out, if a soil can be practically freed from alkali by underdrainage connected with a thorough satura-

³⁰ California Agricultural Experiment Station, Bulletin No. 83.

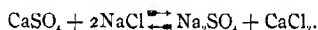
tion by irrigation, it may be centuries before the alkali will accumulate in that soil again when ordinary irrigation only is practiced. It may thus become possible to reclaim large extents of alkaline soil little by little by treating them with an excess of irrigation water in connection with thorough underdrainage. The composition of the alkali on the surface of the soil due to the causes above set forth is shown by the analyses of Hilgard and Weber, which follows:³¹

TABLE SHOWING COMPOSITION OF ALKALI SALTS IN SAN JUAQUIN VALLEY

	TULARE COUNTY.					
	Goshen	People's ditch.	Near Lake Tulare.	Visalia	Lemoore	Tulare Expt. Station
	Surface soil.	Alkali crust.	Surface soil.	Surface soil.	Alkali crust.	Alkali crust.
Soluble salts in 100 parts soil ...	7.40	.....	0.83	1.26	.....	.....
Potassium sulfate.....	.....	.....	.....	.....	.....	small
a Potassium nitrate.....	.....	.....	.....	.....	.....	small
Potassium carbonate (saleratus).....	.....	.....	.....	18.80	.....	.....
Sodium sulfate (Glauber's salt).....	44.24	1.22	31.30 (u)	13.4	chiefly	32.8
Sodium carbonate (sal-soda) ...	32.98	88.09	18.2	45.3	.....	13.16
Sodium chloride (common salt).....	16.74	1.00	.....	4.4	little	31.16
a Sodium phosphate.....	1.97	.....	0.22	10.4	.....	.....
Calcium sulfate (gypsum).....	.....	.....	.....	.....	little	.....
Magnesium sulfate (Epsom salt).....	.....	.....	.....	8.1	moderate	.....
Organic matter.....	1.97	9.21	7.5	.....	.....	5.37

a Very generally present, but not always in quantities sufficient for determination.

54. **Equilibrium Reactions in Solutions of Alkali.**—According to Cameron the classification of alkali into black and white is not entirely satisfactory for practical purposes.³² He suggests a tentative classification according to the predominating reactions which take place in aqueous solutions of the alkali. Where common salt and sulfate of lime are the chief ingredients the reaction is represented as follows:—

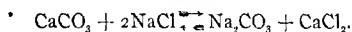


The gypsum in this condition becomes more soluble under the influence of the solution of common salt. Where the calcium chlorid which is formed by this reaction reaches the surface in periods of protracted drought, it gives the surface the appearance of being moist, on account of its highly hygroscopic nature. Cal-

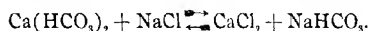
³¹ Bul. 82, Cal. Ag. Ex. Sta., p. 4.

³² Bulletin No. 17, Division of Soils, 26.

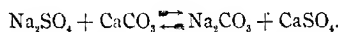
cium chlorid with organic matter forms a dark color and thus the appearance of black alkali may be simulated, although no soluble carbonates may be present. Another type of reaction which may go on is where calcium carbonate and sodium chlorid are the predominating salts in which case the following reaction takes place:—



The calcium chlorid formed in this way would, of course, act as in the previous case. In the presence of carbon dioxid a reaction would take place according to the following formula:—



When the carbonate of lime in solution will reach the surface and lose its excess of carbon dioxid it would naturally revert to the normal state. Magnesium carbonate may partly replace the calcium carbonate in a reaction of this kind. If sodium sulfate and calcium carbonate are the predominating salts in the soil the reaction would assume the following form:



The class of alkali most commonly encountered is that in which the predominating feature is the simultaneous action of solutions of sodium chlorid upon gypsum and calcium carbonate. In this condition there can only be a small amount of sodium carbonates formed and the solubility of the gypsum is also not as great as when calcium carbonate is not present.

55. Adobe Soils.—In many parts of the arid regions of this country which can be recovered for agricultural purposes by irrigation the soil has peculiar characteristics.

The name adobe as commonly used applies to both the sundried bricks of the arid regions of the West and Southwest, and to the materials of which they are composed. The material is described by Russell as a fine grained porous earth, varying in color through many shades of gray and yellow, which crumbles between the fingers, and separates most readily in a vertical direction.³³ The coherency of the material is so great that vertical scarps will stand for many years without forming a noticeable talus slope.

³³ Geological Magazine, 7 : 291-2.

Distribution.—The area over which adobe forms a large part of the surface has not been accurately mapped, but enough is known to indicate that it is essentially co-extensive with the more arid portions of this country. In a very general way it may be considered as being limited to the region in which the mean annual rain-fall is less than twenty inches. It forms the surface over large portions of Colorado, New Mexico, Western Texas, Arizona, Southern California, Nevada, Utah, Southern Oregon, Southern Idaho, and Wyoming. Adobe occurs also in Mexico and may there reach a greater development than in the United States, but observations concerning it south of the Rio Grande are wanting.

In the United States it occurs from near the sea-level in Arizona, and even below the sea-level in Southern California, up to an elevation of at least 6,000 or 8,000 feet, along the eastern border of the Rocky Mountains, and in the elevated valleys of New Mexico, Colorado, and Wyoming. It occupies depressions of all sizes up to valleys having an area of hundreds of square miles. Although occurring throughout the arid region, it can be studied to best advantage in the drainless and lakeless basins in Nevada, Utah, and Arizona.

Composition.—When examined under the microscope, the adobe is seen to be composed of irregular, unassorted flakes and grains, principally quartz, but fragments of other minerals are also present. An exhaustive microscopic study has not been made, but the samples examined from widely-separated localities are very similar. The principal characteristics observed are the extreme angularity of the particles composing the deposit and the undecomposed condition of the various minerals entering into its composition. It is to be inferred from this that the material has not been exposed even to a very moderate degree of friction, and has not undergone subaerial decay before being deposited. Adobe collected, at typical localities is so fine in texture that no grit can be felt when it is rubbed between the fingers; in other instances it contains angular rock fragments of appreciable size.

The composition of the material is illustrated by the following analyses:

ANALYSES OF ADOBE

By L. G. EAKINS,

Constituents.	No. 1. Santa Fe, New Mexico.	No. 2. Fort Wingate, New Mexico.	No. 3. Humboldt, Nevada.	No. 4. Salt Lake City, Utah.
SiO ₂	66.69	26.67	44.64	19.24
Al ₂ O ₃	14.16	0.91	13.19	3.26
Fe ₂ O ₃	4.38	0.64	5.12	1.09
MnO.....	0.09	trace	0.13	trace
CaO.....	2.49	36.40	13.91	38.94
MgO.....	1.28	0.51	2.96	2.75
K ₂ O.....	1.21	trace	1.71	trace
Na ₂ O.....	0.67	trace	0.59	trace
CO ₂	0.77	25.84	8.55	29.57
P ₂ O ₅	0.29	0.75	0.94	0.23
SO ₃	0.41	0.82	0.64	0.53
Cl.....	0.34	0.07	0.14	0.11
H ₂ O.....	4.94	2.26	3.84	1.67
Organic matter ...	2.00	5.10	3.43	2.96
	99.72	99.97	99.84	100.35

Judged by the content of calcium carbonate alone three of the above samples resemble marl.

56. Vegetable Soils.—The heavy soils whose origin has been described are essentially of a mineral nature. The quantity of organic matter in such soils may vary from a mere trace to a few per cent., but they never lose their mineral characteristics. When a soil on the other hand is composed almost exclusively of vegetable mold it belongs to quite another type. Such soils are called tule, peat or muck. In this country there are thousands of acres of peat or muck soils; the largest contiguous deposits being found in Southern Florida. The origin of these soils is easily understood. Whenever rank vegetation grows in such a location as to secure for the organic matter formed a slow decay there is a tendency to the accumulation of vegetable mold in shallow water or on marshy ground and where other conditions are favorable to such accumulations. In Florida the peaty soils have been accumulated about the margins of lakes. During the rainy season the marshes bordering these are partly covered with water, but the vegetation is very luxuriant. The water protects the vegetable matter from being destroyed by fire. It therefore accumu-

lates from year to year and is gradually compacted into quite a uniform mass of vegetable mold.

The ultimate composition of the mold is illustrated in the following table which shows the character of the layers at one, two and three feet in depth:³⁴

	Carbon.	Hydrogen.	Nitrogen.	Volatile matter.
1 foot....	57.67 per cent.	4.48 per cent.	2.24 per cent.	90.60 per cent.
2 feet....	47.07 "	5.15 "	1.40 "	72.00 "
3 feet....	8.52 "	0.53 "	0.31 "	15.00 "

In this last sample, the mold was only three feet deep, resting on pure sand. As the bottom of the deposit is approached the admixture of sand becomes greater and the percentage of organic matter less.

No reliable estimate of the time which has been required to form these deposits can be given, but in the Okeechobee region in Florida the deposit of vegetable mold in some places exceeds ten feet in depth.

The purest vegetable or peat soils contain only small quantities of potash and phosphoric acid, and especially is this true of the Florida deposits which have been formed of vegetable growth containing very little mineral matter.

It is not at all probable that the flora now growing on any particular area of virgin peat contains all the plants that have contributed to its formation. The principal vegetable growths now going to make up the peat soils of Florida are the following:

Common names.	Botanical names.
Saw grass	<i>Cladium effusum</i> .
Yellow pond lily	<i>Nymphaea flava</i> .
Maiden cane grass	<i>Panicum Curtisii</i> .
Alligator Wampee	<i>Pontederia cordata</i> .
Sedge	<i>Cyperus species</i> .
Fern brake	<i>Osmunda</i> "
Mallow	<i>Malva</i> "
Broom sedge	<i>Andropogon</i> "
Arrow Weed	<i>Sagittaria</i> "

The above are only the plants growing in the greatest profu-

³⁴ Wiley: Agricultural Science, 1893, 106 et seq.

sion and do not include all which are now contributing to increase the store of vegetable débris.

57. **Humus.**—The active principle of vegetable mold is called humus, a term used to designate in general the products of the decomposition of vegetable matter as they are found in soils. In peat and vegetable soils are found a mixture of humus with undecomposed or partially decomposed vegetation.

According to Kostyschoff vegetable matter decays under the influence of molds and bacteria.³⁵ Molds alone produce the dark colored matters which give soils rich in vegetable matter, their color. One chief characteristic of humus is its richness in nitrogen. Black Russian soil contains from 4 to 6.65 per cent. of nitrogen. This soil is estimated to contain 60,000,000 organisms per gram and much of the nitrogen which it holds must be in the form of proteid derivatives. The first development in decaying vegetable matter is of bacteria and there is a tendency of the decaying matter to become acid. This causes the death of the bacteria and the ammonia produced thereby neutralizes the acid. The various kinds of mold grow when the reaction becomes neutral. Afterwards the bacteria and the molds develop together. This statement of Kostyschoff is not a very satisfactory explanation of even our limited knowledge of the decomposition of organic matters in the soil. Ammonia and ammonia salts are formed not by the decay of some forms of bacteria but by the activities of other forms. It has been found that in nitrification there are three distinct forms of bacteria concerned in the final products of ammonia, nitrites, and nitrates. Humus always contains easily decomposable matter and consequently the rate of decay in similar conditions at any observed periods is nearly the same. In humus which is produced above the water-level Kostyschoff states that all trace of the vegetable structure is destroyed by the leaves being gnawed and passed through the bodies of caterpillars and wire-worms. Under the water-level the vegetable structure is preserved and peat results. The de-

³⁵ *Travaux de la Société des Naturalistes de St. Petersburg*, 20; *Annales Agronomiques*, 17 : 17.

cay of humus is most rapid in drained and open soils. For this reason the presence of clay in a soil promotes the accumulation of humus. Inferior organisms are the means of diffusing organic matter through the soil. The mycelia of fungi grow on a dead root for instance, ramify laterally and thus carry organic matter outward and succeeding organisms extend this action and the soil becomes darkened in proportion. Humic acid in black soil is almost exclusively in combination with lime.

A more common view of the difference between the formation of humus above and below the water-level is that above the water-level there is a very free access of air and even the harder parts of the leaf skeleton can be oxidized through the agency of bacteria, while under the water-level there is a very limited supply of air and this oxidation cannot proceed as rapidly. The harder parts of the leaf skeleton are preserved, and from the freer access of air humus is oxidized more readily in drained and open soils, and accumulates in clay soils where there is less circulation of air.

The quantity of humus in the soils of arid regions is by no means so great as in those of abundant rain-fall. The influence of aridity on the formation of humus has been fully discussed by Hilgard.²⁸

Few of the upland arid soils of the Pacific coast contain over .4% of humus, that is the "matière noire" of Grandeau. This difference according to Hilgard is of importance because the humus of the soil is the chief repository of one of the most costly of the plant foods, *viz.*, nitrogen.

It must not be inferred however that such soils are very deficient in nitrogenous food since it appears that the humus of the arid soil has a higher percentage of nitrogen than that found in soils with abundant water supply.

The real composition of humus is a matter which has never been definitely determined. Composed as it is of many different but closely related substances it has been difficult to isolate and determine them.

²⁸ Report California Agricultural Experiment Station, 1892, 112.

The following table gives, according to the early views of agricultural chemistry, the composition of the bodies which form the larger part of humus:³⁷

Ulmin and Ulmic Acid.		
Carbon.....	67.1 per cent.	} Corresponding to $C_{10}H_{28}O_{12} + H_2O$.
Hydrogen.....	4.2 "	
Oxygen.....	28.7 "	
Humin and Humic Acid.		
Carbon.....	64.4 per cent.	} Corresponding to $C_{10}H_{24}O_{12} + 3H_2O$.
Hydrogen.....	4.3 "	
Oxygen.....	31.3 "	
Apocrenic Acid.		
Carbon.....	56.47 per cent.	} Corresponding to $C_{21}H_{24}O_{12} + H_2O$.
Hydrogen.....	2.75 "	
Oxygen.....	40.78 "	
Crenic acid.		
Carbon.....	45.70 per cent.	} Corresponding to $C_{24}H_{24}O_{12} + 3H_2O$.
Hydrogen.....	4.80 "	
Oxygen.....	49.50 "	

Aside from these humus compounds, there are others still less known and the action of which is not yet understood; among them are xylic acid, saccharic acid and glucinic acid, besides a brown humus acid containing carbon, 65.8 per cent., and hydrogen, 6.25 per cent., and a black humus acid yielding carbon, 71.5 per cent., and hydrogen, 5.8 per cent.

Berthelot and André ascribe to the insoluble form of humic acid the formula, $C_{18}H_{18}O_7$. This acid loses water slowly at ordinary temperatures and rapidly at 110° forming the insoluble anhydrid $C_{18}H_{14}O_6$. This acid and its anhydrid combine with potash and soda forming insoluble salts in which three atoms of hydrogen are replaced by the metal of the base.³⁸ It is evident that no serious attempt should be made to ascribe formulae to bodies of such a complex nature and variable composition.

The purest forms of these bodies have undoubtedly been made from sugar. The composition of ulmin and humin thus produced according to Mayer is as follows:

³⁷ Mulder: *Chemie der Ackerkrume*, 1: 322; *The Chemistry of Vegetable and Animal Physiology*, Johnston's translation, 146 et seq.

³⁸ Beilstein's *Handbuch der organischen Chemie*, 3d edition, 1: 1109.

	Ulmín.	Humín.
Carbon	63.4 per cent.	63.4 per cent.
Hydrogen.....	4.8 “	4.3 “
Oxygen.....	31.8 “	32.3 “

It is seen that there is but little difference in the composition of the two bodies.³⁹

At the present time we can only regard the various forms of humus bodies as mixtures of many substances mostly of an acid nature and resulting from a gradual decomposition of organic matter under conditions which partially exclude free access of oxygen.

For analytical purposes it is important to separate these bodies by the best approved processes. A further knowledge of their composition can then be obtained by determining the percentages of carbon dioxid and water which they yield on combustion.

58. Artificial Humus.—The highly complex nature of natural humus excludes the possibility of ascribing to it a definite chemical formula. It is also believed in the present state of our knowledge that the bodies characterized by Mulder as humic and ulmic acids cannot be regarded as pure chemical compounds and that the isolation of such pure compounds has never been accomplished.

More reliable data are secured by converting definite compounds such as sugar and starch into a black organic substance of which the composition is more or less definite. This conversion takes place under the influence of heat and of acids or alkalies. Berthelot describes a process for converting sugar into a black substance by the action of hot hydrochloric acid.⁴⁰

The substance thus formed, after the removal of all traces of the acid by prolonged washing in hot water, is brown-black, and amorphous. Its centesimal composition is:—

C.....	66.41
H.....	4.57
O.....	29.02

³⁹ Mayer: *Agrikulturchemie*, 5th edition, 2: first part, 76.

⁴⁰ *Chémie Végétale et Agricole*, Paris, 1899, 4: 123.

A product made from starch in a similar manner is composed of:—

C.....	65.7
H.....	5.0
O.....	29.3

From the above analysis the rational formula $C_{18}H_{14}O_8$ is proposed for this substance and with one molecule of water of hydration $C_{18}H_{16}O_7$.

These compounds resemble very nearly those prepared by Mulder when the differences in degree of desiccation and other changes in the environment of preparation are considered. This substance may be assumed to be humic acid.

59. Salts of Humic Acid.—Berthelot has prepared three potash salts from the humic acid above described which have the following properties:

1. Monobasic salt which is insoluble and which is not broken up even under prolonged washing with water.
2. A tribasic salt which is insoluble but which is slowly decomposed in the cold under the influence of water until finally two-thirds of the alkali originally combined is extracted.
3. A polybasic salt containing a larger quantity of base than the foregoing and which is soluble in water.

It is concluded that humic acid is polybasic, losing a part of its water by simple desiccation and even in water at ordinary temperatures, thus undergoing a kind of dissociation. In this condition it unites with three equivalents of potash, forming insoluble salts. The first is monobasic, very stable and is formed with the evolution of + 18 Calories, practically the same as are produced by the formation of solid alkaline salts with strong mineral acids in a dilute state.

These humic substances like those of the soil, show also under the influence of a base, phenomena of hydration, and afterwards under the inverse action of an acid the effects of spontaneous dehydration by dissociation.

Humic acid is produced like sugars with absorption of heat; that is to say, it contains an excess of energy stored in its car-

bohydrates susceptible of being evolved by their total destruction.

60. Composition of Artificial Humus from Various Materials.—

In order to compare humus substances of different origin Snyder has suggested a method of preparing them without the use of alkaline bodies.⁴¹

Various organic materials were mixed with a large excess of soil poor in humus and exposed to natural weathering for one year. For instance, 200 grams of sugar was mixed with 3000 grams of soil. Cow manure, green clover, meat scraps, wheat flour and old straw were among the materials used.

The humus materials produced from these various substances were obtained by extracting the soil, after treatment with dilute hydrochloric acid and distilled water, with a three per cent. potassium hydroxid solution. The alkaline humus extracts were neutralized with hydrochloric acid, which gave black and brown precipitates of humus materials, which were washed, dried, and prepared for analysis. The precipitated humus materials contained from 5 to 12 per cent. of ash, and had the following ultimate composition, on an ash-free basis:

HUMUS PRODUCED BY						
	Cow manure. Per cent.	Green clover. Per cent.	Meat scraps. Per cent.	Wheat flour. Per cent.	Oat straw. Per cent.	Saw- dust. Per cent.
Carbon	41.95	54.22	48.77	51.02	54.30	49.28
Hydrogen ...	6.26	3.40	4.30	3.82	2.48	3.33
Nitrogen	6.16	8.24	10.96	5.02	2.50	0.32
Oxygen	45.65	34.14	35.97	40.14	40.72	47.07
Total	100.00	100.00	100.00	100.00	100.00	100.00
	Highest. Per cent.			Lowest. Per cent.		
Carbon	57.84	from sugar.		41.95	from cow manure.	
Hydrogen ...	6.26	" cow manure		2.48	" oat straw	
Nitrogen	10.96	" meat scraps		0.08	" sugar	
Oxygen	47.07	" sawdust.		34.14	" green clover.	
						Difference. Per cent.
						15.89
						3.78
						10.88
						12.93

The differences in composition are noticeable. The humus produced by each material, as meat scraps, green clover, or sawdust, is different from the humus produced by every other mate-

⁴¹ Journal of the American Chemical Society, 1897, 19 : 738

rial. There is not a general similarity in composition between the humus produced by any two of the materials. The humus produced by sugar may be taken as a type of a non-nitrogenous humus. The small amount of nitrogen present in the sugar humus has been derived from the nitrogen present in the soil. The humus from meat scraps may be taken as a type of humus produced from a nitrogenous material. The nitrogen content of the humus ranges from about 0.5 per cent. in sugar humus to nearly 11 per cent. in the meat scraps humus. The humus from such materials as meat scraps and green clover must be exceedingly complex, because each material is composed of both nitrogenous and non-nitrogenous compounds, and each class of compounds is capable of being split up into still other compounds, each one having a different action in humification processes. It is evident that any formulas applied to the compounds, as a whole, would, to say the least, fail to express the composition of humus.

Although the proximate composition of humus as yet, can not be given, or formulas assigned to these compounds, the nature of the humus as nitrogenous or non-nitrogenous can be determined.

It would seem best, in the present state of knowledge, to make the divisions on the basis of nitrogen, as:

I. The non-nitrogenous humus group, as sugar humus.

II. The nitrogenous group, divided into three or four sub-groups, as (1) humus containing from one to two per cent. nitrogen, as sawdust humus; (2) humus containing from two to four per cent. nitrogen, as oat straw humus; (3) humus containing from four to eight per cent. nitrogen, as cow manure and clover humus; and (4) humus containing over eight or nine per cent. nitrogen, as meat scrap humus.

Such a division would give an approximate idea of the nature of the materials from which the humus has been derived, as well as indication of its agricultural value.

61. Influence of High Temperature on Humus.—The presence of an abundant supply of humus in a soil is usually regarded as an index of fertility, and in those soils which are deficient in humus, such as sandy and excessively clayey soils, the increase in humus content is an indispensable condition to the production of

permanent fertility. Large deposits of vegetable matter are therefore preserved from decay by cold weather.

The consumption of humus by the growing crop and by oxidation is very much more rapid at high than at low temperature.⁴²

Boussingault pointed out more than 50 years ago that there were no peat-beds in the tropics except at a height of over 3000 feet on the plateaux of the Andes. The humus found in the soil of tropical forests is preserved by the thick vegetable cover and great humidity which prevent the development of a high temperature.

62. Functions of Humus.—Whether humus takes any direct part in the nutrition of green plants is not definitely known. De Saussure held that soluble humus was assimilated directly by vegetables and this is probably the case with those plants, such as mushrooms, which are devoid of chlorophyll.

Leibig held that humic acid is not absorbed by plants and that as such it does not form a part of their food. Humic acid being of a colloidal nature is not well suited to engage in the translations which takes place so readily with crystalline bodies in solution and which readily change their location under the stress of osmotic pressure.

Petermann found however that such bodies could be dialyzed in certain circumstances and he succeeded in passing through membranes highly nitrogenized organic matter of an amber color.⁴³

The author found that sugar canes grown in peat soils contained a quantity of dark colored organic matter in their sap which persisted even in the raw sugar made therefrom.

He further found that the quantity of amid nitrogen in oats was greatly increased when grown on peaty soil.⁴⁴

The chief functions of humus appear to be to modify the physical conditions of the soil with reference to texture, moisture, absorption of heat and mineral matters useful to plants and especially to hold in suitable form for progressive nitrification the partially decayed nitrogenous principles of vegetable matters.

⁴² Breal : *Annales Agronomiques*, 20 : 353.

⁴³ *Annales Agronomiques*, 9 : 237.

⁴⁴ Wiley : *Die landwirtschaftlichen Versuchs-Stationen*, 49 : 193. *Journal American Chemical Society*, 1897, 19 : 605.

63. Soil and Subsoil.—Many subdivisions have been made of the above varieties of soil, but they have little value for analytical purposes. For convenience in description for agricultural purposes, the soil, however, is further divided into soil and subsoil. In this sense the soil comprises that portion of the surface of the ground, usually from four to nine inches deep, containing most of the organic remains of plants and animals and in which air circulates more or less freely for the proper humification of the organic matter, which usually gives a darker color to the soil than to the subsoil. The subsoil proper lies below this, and has usually more characteristic properties, especially in respect of color and texture, as it has been less influenced by artificial conditions of cultivation and the remains of vegetation.

The subsoil extends to an indefinite depth and is limited usually by deposits of undecomposed or partly decomposed rock matter, or by layers of clay, sand or gravel.

Inasmuch, however, as the influence of the subsoil on growing crops is of little importance below the depth of 18 inches the analysis of samples from a greater depth has more of a geological than agricultural value.

Hilgard regards as subsoil whatever lies beneath the line of change of color, or below the minimum depth of six inches. But should the change of color occur at a greater depth than 12 inches, the soil specimen should nevertheless be removed to the depth of 12 inches only, which is the limit of ordinary tillage; then another specimen from that depth down to the line of change, and then the subsoil specimens beneath that line. The depth to which the last should extend will depend upon circumstances. It is always desirable to know what constitutes the foundation of a soil to the depth of three feet at least, since the question of drainage, resistance to drought, etc., will depend essentially upon the nature of the substratum. But in ordinary cases 10 or 12 inches of subsoil will be sufficient. The sample should be secured in other respects precisely like that of the surface soil, while that of the material underlying this subsoil may be removed with less exactness, perhaps at some ditch or other easily accessible point, and should not be broken up like the other specimens.

In the method of soil sampling adopted by the Royal Agricul-

tural College of England, the soil is regarded as that portion of the surface of the ground which is reached by ordinary tillage operations, generally being from six to nine inches' deep; the subsoil is that portion which is ordinarily not touched in plowing.

It is evident that no rigid definition of the difference between soil and subsoil can be made as the one gradually merges into the other. In general it may be said from the practical point of view that the soil is that part of the surface of the field extending to a depth of nine inches or to the depth turned by good plowing and the subsoil the layer of nine inches in depth immediately underneath the soil.

PART SECOND

SAMPLING SOILS FOR ANALYSIS

64. General Principles.—It would be unwise to attempt to give any single method of soil sampling as the only one to be practiced in all circumstances. In the methods which follow it is believed will be found directions for every probable case. The particular method to be followed will in each case have to be determined by circumstances.

The sole object in securing a sample of soil should be to have it representative of the type of soils to which it belongs. Every precaution should be observed to have each sample measure up to that standard.

The physical and chemical analyses of soils are long and tedious processes and are entirely too costly to be applied to samples which are not representative.

The particular place selected for getting the samples as well as the method employed are also largely determined by the point of view of the investigations. The collection of samples to illustrate the geological or mineralogical relations of soils is quite a different matter from gathering portions to represent their agricultural possibilities. In a given area the sum of plant food in the soil would only be determined by the analyses of samples from that particular field, while samples illustrating geological relations could or should be got at widely distant points. Again the chemist is content with a sample of a few hundred grams in weight while the physicist would require a much larger quantity. Much popular ignorance exists respecting the importance of the collection of soil samples. As an illustration of this may be cited a recent instance in which a sample of soil was received by the author with a request for a complete analysis and a statement of the kinds of crops it was suited to grow. No data relating to the locality from which the sample was taken accompanied this request. The sample itself, which weighed a little less than 3.6 grams, was not a soil at all in an agricultural sense but a highly ferruginous sand.

The collector of samples who understands the purpose for which he is working will find among the approved methods which follow some one or some combination of methods, by means of which his work can be made successful. In these cases it is the collector rather than the method on which reliance must be placed to secure properly representative samples.

65. General Directions for Sampling.—The locality having been selected which presents as nearly as possible the mean composition of the field a square hole is dug with a sharp spade to the depth of 18 inches. The walls of this hole should be smooth and perpendicular. The soil to the depth of from six to nine inches is then removed from the sides of the hole in a slice about four inches thick; or the sample of soil may extend to the depth indicated by a change of color. Any particles which fall into the bottom of the hole are carefully collected and added to the parts adhering to the spade. The whole is thrown into a suitable vessel for removal to the laboratory. The sample of soil having been thus secured, the subsoil is treated in the same way. It is evident also that the sample may be secured by removing the soil from the hole directly and then securing the sample of the subsoil. To insure uniformity in the samples, it is well to get several of them from the same field. Where more than one sample of the same type is collected it is advisable to mix all the sub-samples in the field, remove large sticks, stones, roots, etc., and select a general sample of from three to five kilograms. The characters and quantity of the débris removed should be carefully noted.

It is sometimes desirable to get samples of the subsoil to a greater depth than 18 inches. A post-hole auger or large wood auger will be found very useful for this purpose. It is rarely necessary to get samples of subsoil to a greater depth than six feet. The geological formation and the general topography of the field should be noted, also the character of the previous crops, kind and amount of fertilizers employed, character of drainage and any other data of a nature to give a more accurate idea of the forces which have determined the physical and chemical properties of the sample. In case of a virgin soil the character of the natural vegetation is to be noted.

66. Method of Hilgard.—Hilgard recommends that samples

should not be obtained indiscriminately from any locality, but that consideration should be given to the chief varieties of soil which, with their inter-mixtures, make up the cultivable area of the region.⁴⁵

As a rule, and whenever possible, samples should represent soils that have not been cultivated, or are otherwise likely to have been changed from their original condition of virgin soils and not ground frequently trodden over such as roadsides, cattle paths, or small pastures, squirrel holes, stumps, or even the foot of trees, or spots that have been washed by rains or streams, so as to have experienced a noticeable change, and not be a fair representative of their kind. The method proposed therefore is intended only for virgin soils. He further suggests that the normal vegetation, trees, herbs, grass, etc., should be carefully observed and recorded, and spots showing unusual growth whether in kind or quality be avoided as such are likely to have received some animal manure or other addition.

Specimens should be secured from more than one spot judged to be a fair representative of the soil intended to be examined as an additional guarantee of a fair average.

After selecting a proper spot pull up the plants growing on it, and scrape off the surface lightly with a sharp tool to remove half-decayed vegetable matter not forming part of the soil. Dig a vertical hole, like a post-hole, at least 20 inches deep. Scrape the sides clean so as to see at what depth the change of tint occurs which marks the downward limit of the surface soil; and record it. Remove at least half a bushel of the earth above this limit, and on a cloth (jute bagging should not be used for this purpose, as its fibers, etc., become intermixed with the soil) or paper break it up and mix thoroughly, and put up at least a pint of it in a sack or package for examination. This specimen will, ordinarily, constitute the soil. Should the change of color occur at a less depth than six inches the fact should be noted, but the specimen removed to that depth nevertheless, since it is at least a depth to which rational cultures can be supposed to reach.

In case the difference in the character of a shallow surface soil

⁴⁵ Bulletin 68 Division of Chemistry, 60 et seq.; Tenth Census, 1880,

5 : 67 et seq.

and its subsoil should be unusually great, as may be the case in tulle or other alluvial lands or in rocky districts, a separate sample of that surface soil should be got, besides the one to the depth of six inches.

Specimens of salty or alkali soils should, as a rule, be secured only toward the end of the dry season, when they will contain the maximum amount of the injurious ingredients which it may be necessary to neutralize.

Whatever lies beneath the line of change, or below the minimum depth of six inches, will constitute the subsoil. Should the change of color occur at a greater depth than twelve inches the soil specimen should nevertheless be obtained to the depth of twelve inches only, which is the limit of ordinary tillage; then another specimen from that depth down to the line of change, and then the subsoil specimen beneath that line.

Hilgard justly calls attention to the fact that all peculiarities of the soil and subsoil, their behavior in wet and dry seasons, their location, position and every circumstance in fact, which can throw any light on their agricultural qualities or peculiarities should be carefully noted and the notes sent with the samples. Unless accompanied by such information, samples can not ordinarily be considered as justifying the amount of labor involved in their examination. When the sample is not to be used immediately it should be air-dried as soon as possible. Otherwise the activity of the organisms it contains will continue and profound changes in composition may ensue, especially in the nitrogenous matters which may be present.

When available the geological maps of the region where samples are secured should be consulted in order that the information respecting the origin of the soil may be utilized.

The kind of analyses to which a sample is to be subjected also largely determines the method to be pursued in selecting it: For instance, a sample to be used for determining the size of the particles therein, may be obtained in quite a different manner from that designed only for the determination of moisture, or for partial or complete physical and chemical analysis.

67. In the directions collated by Richards and which have been largely followed by the correspondents of the Department of Ag-

riculture, it is recommended to select in a field, four or five places, at least, per acre, taking care that these places have an homogeneous aspect, and represent as far as possible the general character of the whole ground.⁴⁶ If the field, however, present notable differences, either in regard to its aspect or its fertility, the samples gathered from the different parts must be kept separate.

The sampling of arable soil should be made only after the raising of the crop and before it has received any new manure. In other soils the sample should represent only spots that have not been cultivated.

68. Caldwell advises that according to the purpose of the analysis samples be secured:⁴⁷

a, from one or from several spots in the field, in order to subject each sample to a separate analysis; or

b, for an average representation of the soil of the whole field; in this case, several portions of earth are gathered from points distributed in a regular manner over the field, all of which are most carefully mixed together, and from four to six kilograms of the mixture, free from any large stones, are preserved as the average sample.

An excavation in the soil from 30 to 50 centimeters deep, or through to the subsoil, and from 30 to 50 centimeters square, with one side as nearly vertical as possible is made and a slice taken from this side of uniform thickness throughout, weighing from four to six kilograms. If the subsoil is to be examined, a sample of it should be removed in the same manner as directed for the upper soil, to the depth of about 20 centimeters.

If the character of the soil varies materially in different parts of the field, samples from several spots should be analyzed separately.

A small portion of the sample should be put at once in a well-stoppered bottle; the remainder may be allowed to become air-dried, by exposing it in a thin layer, in summer, to the common temperature in the shade, or, in winter, to that of a warm room, or a moderately warm drying-chamber, heated to 30°-40°; in either case it should be carefully protected from dust.

⁴⁶ Bulletin 10 Division of Chemistry, 33.

⁴⁷ Caldwell's Agricultural Analysis, 166.

At the time of getting the sample of the soil, observations should be made in regard to the following points:

- a. The geognostic origin of the soil.
- b. The nature of the underlying strata, to the depth of from one to two meters, if practicable.
- c. The meteorology of the locality, by consulting meteorological records, if possible; otherwise, by the general opinion of the neighborhood; in this connection, the height of the locality above the level of the sea should be noted also.
- d. The management and rotation of crops in previous years.
- e. The character of the customary manuring.
- f. The amount of the crops removed in the preceding year, and, if possible, the average amount of each of the more important crops yielded by the field.
- g. The practical judgement of neighboring farmers in regard to the field.

Caldwell's method is practically identical with that of Wolff which was one of the earliest of the systematic schemes for getting soil samples.⁴⁸

69. Method of the Official Agricultural Chemists.⁴⁹—Surface accumulations of decaying leaves, etc., are removed and a slice of uniform thickness from the surface to the desired depth secured. To eliminate the effects of accidental variations in the soil, select specimens from five or six places in the field and remove several pounds of the soil, to the depth of six inches, or to the change between the surface soil and the subsoil, in case such change occurs between the depth of 6 and 12 inches. In no case is the sample to be got to a greater depth than 12 inches. If the surface soil extend to a greater depth, a separate sample below the depth of 12 inches is to be obtained. If the surface soil extend to a depth of less than six inches, and the difference between it and the subsoil is unusually great, a separate sample of the surface soil is secured, besides the one to the depth of six inches.

The depth to which the sample of subsoil is secured will depend on circumstances. It is always necessary to know what

⁴⁸ *Zeitschrift für analytische Chemie*, 8 : 87.

⁴⁹ *Bulletin 46 Bureau of Chemistry*, 71.

constitutes the foundation of a soil, to the depth of 3 feet at least, since the question of drainage, resistance to drought, etc., will depend essentially upon the nature of the substratum. But in ordinary cases 10 or 12 inches of subsoil will be sufficient for the purposes of examination in the laboratory. The specimen is obtained in other respects precisely like that of the surface soil, while that of the material underlying this subsoil may be removed with less exactness, perhaps at some ditch or other easily accessible point, and should not be broken up, but left, as nearly as possible, in its original state. Mix these soils intimately, remove any stones, shake out all roots and foreign matters, expose in thin layers in a warm room till thoroughly air-dry, or dry in an air-bath at a temperature of not above 40°.

The soil is rapidly dried to arrest nitrification. It is not heated above 40° lest there be dissipation of ammonium compounds, or a change in the solubility of the soil. The normal limit to which the soil may be heated in place by the sun's rays should not be exceeded in preparing a soil for an agricultural chemical analysis.

Five hundred grams or more of the air-dried soil, which may be either the original soil or that which has been passed through a sieve of coarser mesh, are sifted through a sieve with circular openings one-half millimeter in diameter, rubbing, if necessary, with a rubber pestle in a mortar until the fine earth has been separated as completely as possible from the particles that are too coarse to pass the sieve. The fine earth is thoroughly mixed and preserved in a tightly stoppered bottle, from which the portions for analysis are weighed.

The coarse part is weighed and examined microscopically or with Thoulet's solution described in part fifth.

70. Method of the Official French Commission.—The official French commission emphasizes the fact that the sample of soil used for analysis, should represent a layer of equal thickness through the total depth of its arable part.⁵⁰ An analysis of the subsoil secured in the same way, will often be useful to complete the data of the soil study.

⁵⁰ *Annales de la science agronomique*, 8th year, 1 : 240, et seq. The commissioners were Messrs. Risler, Grandeau, Joulie, Schloesing and Müntz.

First of all, according to this authority, it is necessary to determine the point of view from which the sample is to be obtained. If the object is a general study, having for its aim the determination of the general composition of the soils of a definite geological formation, the sample should be of such a nature that the different characteristics of the soil alone should enter into consideration without paying any attention to its accidental components, which have been determined by local causes, such as are produced by continued high cultivation, the application of abundant fertilizers, or the practice of a particular line of agricultural industry. The samples of soil therefore, with such an object in view, should represent parts of the earth which are beyond the reach of the causes mentioned above and which tend to modify the nature of the primitive soil. In such a case it is the soil which has not been modified, or better still, virgin soil, such as is found in the woodlands and prairies, which should be used for a sample, choosing those places in which the geological formation is most perfectly characterized. In such a case a sample from one spot corresponding to the conditions before mentioned, would be the best for the purposes in view. The sample would thus represent a true type to be studied, not one of a mean composition got by sampling from different localities and mixing them into a homogeneous parcel. This last method of proceeding may introduce into the sample earth modified by culture or by influences purely accidental. However, it would be wise, in a region characterized by the same geological formation, to secure a certain number of samples in different localities, and examine singly each one of them in order to be assured that there is a uniformity of composition in the whole of the soils.

If, on the contrary, it is the purpose of the investigation to furnish information to the cultivator concerning the fields which are worked, it is necessary to approach the problem from a different point of view. In this case the earth which is under cultivation should be first of all considered with all the modifications which nature causes or practical culture has caused in it. But it often happens that upon the same farm the natural soil is variable, caused either by the washings from the adjacent soils, by the ac-

cumulation at certain points of deposits formed from standing water, or from other reasons. In such a case it would be necessary to get samples from every part of the field which exhibited any variation from the general type, in order to get a complete mean sample of the whole. It is necessary to be on guard against making a mixture of these different lots which would neither represent the different soils constituting the farm nor their mean composition. It would be better to examine each of these samples alone and then from those parts which appear to have a similar composition, to get a general sample for the mean analysis.

Most often it is necessary to confine our studies to the really important part of the farm the composition of which would have a practical interest. The aspect of the spontaneous vegetation in such a case, will often serve as a guide to determine the parts of the farms which are similar in nature. The sample should represent the arable layer, properly so-called, that is, that part of it which is stirred by the agricultural implements in use and in which the root system of the plant takes its greatest development and which is the true reservoir of the fertilizing materials.

When a trench is dug in the soil it is easy to distinguish the arable layer from the subsoil. In the first place, its color is different, generally being modified by vegetable *débris* which forms the supply of humus. The depth of the arable layer is variable, but it is most frequently between 200 and 300 millimeters. In the analysis the depth and layers should be indicated since the chemical composition of the earth varies according as the sample is taken to a greater or less depth. As an example of this it may be said that the quantity of nitrogen decreases in general in proportion as the depth of the layer is increased. The sample therefore, should be limited exactly to the arable layer of soil.

The latest directions for soil sampling according to the accepted French methods are described by Deherain.⁵¹

Since the sampling is the first step in the study of the soil in the laboratory it is highly important that it be properly done. If the field be a large one the surface as a whole should first be carefully examined to determine the degree of homogeneity. If this first view shows the presence of different types of soils as many

⁵¹ *Traité de Chimie Agricole*, 1902 edition, 396.

samples as there are different types should be secured. The samples are then to be secured with a spade as already described. At Grignon the samples are obtained from eight different places. The subsamples thus secured are thoroughly mixed and reduced by continued division to the quantity required. If the object be to determine the moisture in the sample it is spread out on paper, mixed by hand, the pebbles removed and 20 grams of the fine earth placed in the oven and dried for 10 or 12 hours.

The rest of the sample left to air dry for some days if too wet serves to form masses of from one to one and a half kilograms reserved for analysis.

In sampling it is necessary to remove from the surface the living and dead vegetation which covers the soil. With a spade a square hole is then dug to the depth of about 500 millimeters; in other words, to a depth considerably exceeding that of the arable layer. Afterwards on each of the four sides of the hole there is removed by the spade, a prismatic layer of the arable portion of a thickness equal to its depth. The samples thus obtained are united together and carefully mixed for the purpose of forming a sample for analysis. If there are large stones they are removed by hand and their proportion by weight determined.

In all cases it would prove useful to get a sample of the subsoil which is far from playing a secondary rôle. The rootlets bury themselves deeply in it and seek there a part of their nourishment. The subsoil, therefore, furnishes an important addition to the alimentation of the plants. For sampling the subsoil a ditch is dug of sufficient depth, say one meter, and the arable soil carefully removed from the top portion. Afterwards pieces are taken from the four sides of the hole at variable depths, which should always be indicated, and which should extend in general, from six to eight-tenths of a meter below the arable soil since it is demonstrated that the roots of nearly all plants go at least to this depth. The analysis of the subsoil, however, is less important than that of the soil, properly so-called, because the agronomist does not act directly upon it and takes no thought of modifying it and enriching it as he does the layer of arable soil. But the composition of the subsoil is a source of information capable of explaining certain cultural results and capable sometimes, of lead-

ing to the correct way of improving the soil, as in cases where the subsoil can be advantageously mixed with the superficial layer.

71. In the method of soil sampling adopted by the German Experiment Stations it is directed that the samples of soil should be secured according to the extent of the surface to be sampled, in 3, 5, 9, 12 or more places at equal distances from each other.⁵² They should be cut in perpendicular sections to the depth turned by the plow; and for studies of the subsoil to a depth of from 60 to 90 centimeters. The single samples can be either examined separately or carefully mixed and a suitable portion of the mixture transfer to this place.

The directions given by König for soil sampling are those prescribed by the Association of Agricultural Experiment Stations of the German Empire.⁵³ He adds that the different samples should be mixed together only when they are practically alike as determined by outward appearance or by testing for carbonate of lime with hydrochloric acid. If the several portions of the soil removed develop any peculiarities separate samples should be made of all those displaying like characteristics. Instead of a spade, an auger or American post-hole auger may be used.

72. **Wahnschaffe** insists on rather a fuller preliminary statement to accompany soil samples but gives essentially the method of Wolff with some unimportant variations which add little to the value of the process.⁵⁴

73. **Method of Peligot.**—The getting samples of soil of which the physical and chemical properties are to be determined is a delicate operation.⁵⁵ These samples should represent as nearly as possible the mean of both the good and bad qualities of a soil.

In the field selected are chosen a certain number of places at least four or five per hectare. The spots selected should have a homogeneous appearance resembling as nearly as possible the general aspect of the field.

⁵² Die landwirtschaftlichen Versuchs-Stationen, 38 : 291 and 309.

⁵³ Untersuchung landwirtschaftlich und gewerblich wichtiger Stoffe, 2nd edition, 4.

⁵⁴ Anleitung zur wissenschaftlichen Bodenuntersuchung, 17.

⁵⁵ Traité de Chimie analytique appliqué à l'Agriculture, 1883, 149.

By means of a spade a few kilograms of earth are removed to the depth of the subsoil being careful to include in the sample no accidental detritus which the upper part of the soil especially may contain. The samples should be secured immediately after the crop is harvested and before any fresh fertilizer is applied. The samples are carefully mixed and placed in a glass bottle or flask.

The sample of subsoil is obtained in the same manner. If the field presents notable differences in appearance or fertility all the samples should be examined separately.

74. Sampling with an Auger.—When small samples only are required for partial or preliminary study they are conveniently secured by the method recommended by Whitney.⁶⁶

An ordinary wood auger, two and one-half inches in diameter is so arranged as to admit of additions to the stem to enable the operator to get samples at different depths. It may be fitted with a short piece of gas pipe for a handle and the several pieces of which it is composed may be taken apart and carried in a knapsack.

In sampling the boring is continued until a change in color shows that the subsoil has been reached. The auger cuts a very clean sample save in excessively sandy soil. After the soil sample is secured the hole is cleaned out and the sample of subsoil removed by the same instrument. In sampling heavy soils the auger should be removed at least once for each depth of six inches.

It is evident that the auger could not be used to advantage in sampling gravelly soils. The soil is conveniently preserved in heavy cloth bags of which the usual size is six by eight and one-half inches. Where larger samples are required the size of the bag is correspondingly increased. Each bag is to be tagged or labeled to correspond with the entry in the note book.

Samples to determine the amount of empty space in a soil are secured as follows: The sampler is a piece of brass cylinder about nine inches long and one and a half inches in diameter. A piece of clock spring is soldered in one end and sharpened to give a good cutting edge. This arrangement permits the sample to pass into the cylinder without much friction. The area enclosed by the clock spring is accurately determined and a mark is placed in the cylinder six inches from the cutting edge. The apparatus is driven

⁶⁶ Bulletin 35 Division of Chemistry, 108.

into the soil to a depth of six inches, a steel cap being used to prevent the hammer from injuring the cylinder. The earth is next removed from about the cylinder with a trowel, and the separated earth is cut smoothly off by a sharp knife and removed together with its brass envelope. The sample is taken to the laboratory in a cloth bag, dried and weighed. The specific gravity of the sample is determined⁵⁷ and the volume occupied by a given amount calculated.

75. Sampling for Moisture Determination.—In the method of Whitney a number of brass tubes is provided 9 inches long and $\frac{3}{4}$ inch in diameter and with a mark 6 inches from the bottom.

The tube is pushed down into the soil to the mark and the sample of soil removed with the tube. There is but little danger of the sample dropping out of the tube even in sandy soils. When the tube is withdrawn each end is capped with a rubber finger tip making a perfectly air tight joint. The tubes containing the samples can be kept several days with no fear of losing moisture. This method is especially useful in getting samples from observers in different localities who can enclose the tubes in a cloth sack and send them to the laboratory by mail daily or at stated intervals. A tube of the size given holds about fifty grams of soil.

76. Sampling to Determine the Permeability of Soil to Water or Air.—Whitney determines the permeability of soil or subsoil to water or air in the following manner:⁵⁷

An excavation two feet square and 18 inches deep is made in the soil. On one side of this hole the sample of soil or subsoil is secured by means of a narrow saw blade and a sharp carving knife. The sample of soil should be two inches square and from three and a half to four inches long. It is placed in a brass cylinder three inches long and three and a quarter inches in diameter. The open space in the cylinder is filled with paraffin heated just to its melting point. As the paraffin cools the upper surface should be kept stirred to prevent the mass when set from receding from the square column of soil. Care must be taken to keep the paraffin from the ends of the soil columns and these should be left, as far as possible in their natural condition.

The rate of percolation of the water may be determined at the

⁵⁷ Bulletin 35 Division of Chemistry, 111.

time the sample is secured. For this purpose an additional section of brass tube two inches long is fastened to the one holding the sample by a rubber band. An iron rod is driven into the earth carrying a retort stand ring supporting a funnel filled with fine gravel. The lower end of the soil column in the brass cylinder is placed on this gravel. Water is next carefully poured upon the top of the sample of soil being careful not to disturb the surface. The surface of the sample may be protected with a little fine sand. The water may be poured on the paraffin thus affording an additional protection to the soil surface. When the water begins to drop from the funnel a graduated glass is set under it and the time required for a given volume to pass through under an initial pressure of two inches is noted. The volume required represents one inch in depth over the four square inches of soil surface, *viz.*: four cubic inches.

77. Method of the Royal Agricultural Society.⁸⁸—Have a wooden box made, 6 inches long and wide, and from 9 to 12 inches deep, according to the depth of soil and subsoil in the field. At one of the selected places mark out a space of 12 inches square; dig around it in a slanting direction a trench, so as to leave undisturbed a block of soil, with its subsoil, from 9 to 12 inches deep; trim this block to make it fit into the wooden box, invert the open box over it, press down firmly, then pass a spade under the box and lift it up and gently turn it over.

In the case of very light, sandy, and porous soils, the wooden box may be at once inverted over the soil and forced down by pressure, and then dug out.

Proceed in the same way for collecting the samples from all the selected places in the field, taking care that the subsoil is not mixed with the surface soil. The former should be sampled separately.

In preparing the plot for the gathering of the sample, take care to have it lightly scraped so as to remove any débris which may be accidentally found there.

The different samples thus procured are emptied on a clean, boarded surface, and thoroughly mixed, so as to incorporate the different samples of the same field together. The heap is then

⁸⁸ Bulletin 10, Division of Chemistry, 33.

divided into four divisions, and the opposite quarters are put aside, taking care to leave the two remaining ones undisturbed; these are thoroughly mixed together, the heap divided into quarters, and the opposite ones taken away as before. This operation of mixing, dividing into quarters and taking away the opposite quarter is continued until a sample is left weighing about 10 or 12 pounds.

Thus is obtained the average sample of the soil. Of course where only a single sample is desired from the field this method of quartering is not resorted to, but the bottom of the box is nailed directly on and sent to the laboratory, where the soil is to be analyzed. The above method has been modified by Lawes as follows:

78. Method of Lawes.—In the method of sampling proposed by Lawes a steel frame 10 by 12 inches, and nine inches deep open at top and bottom is driven into the earth until its upper edge is level with the surface of the soil.⁵⁹ All above-ground vegetation is then cut off as closely as possible with scissors. The soil within the frame is then removed exactly to the depth of the frame, and immediately weighed. It is then partially dried, and mechanically separated by a series of sieves, all visible vegetable matter being at the same time picked out. The stones and roots and the remaining soil are thus separated, and the determinations of dry matter, nitrogen, etc., are made in the separated soil after being finely powdered. The loss of water at each stage of preparation and on drying the samples as analyzed is also carefully determined. This method which requires the soil to be gathered to an arbitrary depth of nine inches, could not be used when samples of strictly arable soil are to be studied.

79. Method of Warrington.—Dyer at the suggestion of Lawes and Gilbert recommends the general adoption of the Rothamstead method of sampling described by Warrington.⁶⁰

This method is an amplification of that just described.

A frame made of stout sheet iron, in shape a rectangular prism open at top and bottom, is driven into the soil by repeated blows

⁵⁹ Journal of the Royal Agricultural Society, [2] 25 : 12.

⁶⁰ Bulletin 62, Division of Chemistry, 86; Office of Experiment Stations, 1892, Bulletin 8, 39.

of a wooden rammer till the soil has the same level inside and outside the frame. The soil inside the frame is then cut out and constitutes the sample of the first depth, or surface soil. That the frame is accurately emptied is ascertained by trials with a wooden gauge of the same depth as the iron frame. If a sample of the next depth is desired the soil is cleared away around the outside of the frame till the level is reduced to that of the bottom of the frame; the frame is driven down again and the former operations are repeated.

Soil sampling at Rothamsted is usually carried down to three depths, but in a good many cases it has been carried down to 12 depths. The area of the sampling frame used for the first depth is usually 144 square inches (12 by 12 inches) a smaller frame (six by six inches) being used for the succeeding depths.

The iron frame has a stout rim along its upper edge to increase its strength. The best sampling frame is made of cast steel; this form of frame needs no rim.

When the soil sampling is carried below the first depth care must be taken when digging around the frame that each depth of soil removed is placed by itself, so that when the pit is filled in the soil may be returned to its proper position. A record must be kept of the place where the sampling is conducted, as a soil can not be accurately sampled twice in the same place.

Each sample of soil is weighed as soon as it is removed from the frame, and is put into a bag by itself. When the soil reaches the laboratory it is at once broken up by hand into small pieces, and laid on paper trays, which are placed on the shelves of a storeroom kept at a temperature of about 55° till thoroughly dry; each sample is then returned to its bag. This immediately drying the soil at a low temperature is essential if changes in the organic matter, and especially nitrification, are to be stopped. This practice dates at Rothamstead from 1877. After drying the soil it may be stored till leisure is found for further work. Each bag is then weighed. The soil is crushed and passed through a $\frac{1}{4}$ inch sieve; the stones that do not pass through this sieve are weighed. All that passes through the sieve is thoroughly mixed and a sufficient quantity is finely powdered for analysis. Mixed samples are

prepared after the soil has passed through the $\frac{1}{4}$ inch sieve or after it has reached the stage of fine powder.

80. **Grandeau** recommends without change the methods of soil sampling adopted by the Eastern Agricultural Station of France.⁶¹ In sampling soils there are two cases to be considered; first a homogeneous soil and second, a soil variable in its appearance and composition. First, if the soil is homogeneous, being of the same geological formation it will be sufficient to get a mean sample in accordance with the following directions:

The field is first divided by diagonals or by transverse lines the direction of which need not be fixed in advance but as inspection of the form and configuration of the field may indicate. In the ordinary conditions of homogeneity (marly, granitic, argillaceous or silicious soils) it will be sufficient to select about five points per hectare from which the samples are to be taken. These points having been determined the surface is cleaned in such a way as to remove from it the detritus which may accidentally cover it; such as dry leaves, fragments of wood, foreign bodies, etc. The surface having been prepared, (five-tenths to six-tenths square meter) a hole is dug four-tenths of a meter long and as wide as the spade employed. The sides should be as nearly vertical as possible. As to depth it varies with the usage of the country in regard to tillage. The layer of arable earth is what in effect properly constitutes the soil. It ought not to be mixed with any fragments of the subsoil. When the hole is properly cleaned the samples are secured with a spade from the sides of the excavations. About five kilograms are sufficient. The soil is placed in a proper receptacle as it is removed from the hole.

This operation is repeated on as many points as may be necessary to obtain a mean sample of the soil of the whole field.

All the samples are now collected on a table sufficiently large, and intimately mixed together. Two samples, each of about five kilograms, are then made from the mixed material. One sample is immediately placed in bottles and carefully stoppered and sealed; the other is dried in the sun or on the hearth of a furnace. When sufficiently dry the second sample is also placed in bottles and well stoppered. While mixing the samples, pebbles, etc., of

⁶¹ *Traité d'Analyse des Matières Agricoles*, 3d edition, 1897, 1 : 131.

the size of a nut and larger are removed, the weight of the rejected matter being determined. The nature of the pebbles should also be noted; whether silicates, limestone, etc.

The sample of subsoil is secured in exactly the same manner, using the same holes from which the samples of soil were removed. The nature, the aspect and the order of the strata will indicate the depth to which the subsoil should be sampled. In general, a depth equal to that of the sample of soil will be sufficient. The depth to which the roots of cultivated plants reach is also a good indication in selecting a sample of the subsoil. In forests the sample of subsoil should be obtained from four to five-tenths of a meter below the plane where the horizontal roots lie.

If the soil in respect of its geological formation, its fertility or its physical aspect presents great differences, special samples should represent each part in accordance with the directions given above.

81. Wolff suggests that a hole 30 centimeters square be dug perpendicularly and a section from one of the sides removed for the sample generally to the depth of 30 centimeters the sample shall be regarded as soil and to the additional depth of 30 centimeters as subsoil.⁶² Local conditions may require a proper variation from these dimensions. The thickness of the section may vary according to the quantity of the sample desired. For analytical purposes, five kilograms will usually be sufficient. When culture experiments are also contemplated a larger quantity will be required. Further suggestions in regard to sampling are found in the directions already given from Caldwell.

82. *Method of Wahnschaffe.*—The method of sampling advised by Wahnschaffe is but little different from that of Wolff already mentioned.⁶³

With a spade a square sample hole is dug having its sides perpendicular to the horizon. The soil which is removed is thrown on a cloth and carefully mixed. From the whole mass a convenient amount is next removed care being taken not to include any roots. In a similar manner it is directed to proceed for the sample of subsoil. At first the subsoil should be removed to a depth

⁶² Zeitschrift für analytische Chemie, 8 : 87.

⁶³ Anleitung zur wissenschaftlichen Bodenuntersuchung, 2nd edition.

of two or three decimeters. The number and depth of subsequent samples will depend chiefly upon the character of the soil. Where sampling extends to the depth of two meters the use of a post-hole auger is recommended.

The samples should not be too small. In general from two to three kilograms should remain after all preliminary sampling is finished.

83. Instruments Employed in Sampling.—In general a sharp spade or post-hole auger is quite sufficient for all ordinary sampling but for certain special purposes other apparatus may be used.

The instrument which is used by King consists of a thin metal tube of a size and length suited to the special object in view, provided with a point which enables it to cut a core of soil smaller than the internal bore of the tube and at the same time make a hole in the ground larger than its outside diameter.⁶⁴ Its construction is shown in figure 9, in which A B represents a soil tube in-

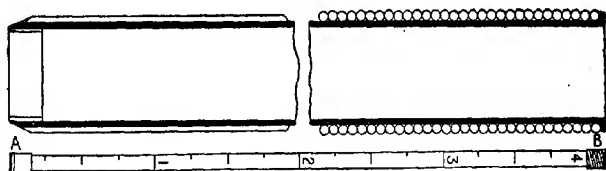


Fig. 9.

tended to get samples down to a depth of four feet. A' is an enlarged cross-section of the cutting end of the tube, which is made by soldering a heavy tin collar, about three inches wide, to the outside of a large tube allowing its lower end to project about one-half an inch. Into this collar a second one is soldered with one edge projecting about one-quarter of an inch and the other abutting directly against the end of the soil tube. Still inside of this collar is a third about one-half an inch wide which projects beyond the second and forms the cutting edge of the instrument.

The construction of the enlarged head of the tube is shown at B'. It is formed by turning a flange on the upper end of the tube and then wrapping it closely with thick wire for a distance of

⁶⁴ Seventh Annual Report Wisconsin Experiment Station, 161.

about three inches, the wire being securely fixed by soldering. The soil tube should be as light as possible not to buckle when being forced into the ground, and the cutting edge*thin. The brass tubing used by gas fitters in covering their pipes has been found very satisfactory for ordinary sampling. With a one inch soil tube four feet long it is possible to get a clear continuous sample of soil to that depth by simply forcing the tube into the ground with the hand and withdrawing it, or the sample may be had in sections of any intermediate length. Later in the season when the soil becomes dryer it is necessary to use a heavy wooden mallet to force the tube, and this should be done with light blows.

The closeness with which it is possible to duplicate the samples in weight by this method will be seen below, where from each of four localities three samples were secured from the surface to a depth of four feet.

SHOWING VARIATIONS IN THE DRY WEIGHT OF TRIPPLICATE
SAMPLES OF SOIL

	A.	B.	C.
I. Surface to four feet.....	716.6 gms.	715.5 gms.	710.3 gms.
II. Surface to four feet.....	715.4 gms.	687.1 gms.	731.2 gms.
III. Surface to four feet.....	654.0 gms.	688.3 gms.	709.0 gms.
IV. Surface to four feet.....	714.0 gms.	687.8 gms.	719.3 gms.

These four series of samples were got at the four corners of a square 12 feet on a side and serve to show how much samples may vary in that distance. The large difference shown in III, A is due to the fact that the soil tube penetrated a hole left by the decay of a rather large root as shown by the bark in the sample. When it is desired to determine accurately the dry weight of the soil per volume the cutting joint of the tube should be made of tool steel, bored accurately to a standard diameter and tempered.

§4. Auger for Sampling.—It has already been said that the ordinary auger used for boring fence post-holes may be used to advantage in sampling soil. Large wood augers can also be used to advantage for the same purpose. For special purposes, however, other forms of augers may be used.

Norwacki and Borchardt have described a new auger for sampling soil for analytical purposes.⁶³

In figure 12, A, B and C show the general exterior and interior form of the instrument. The handle is hollow and made of iron gas pipe covered with leather. On the inside of this, in the mid-

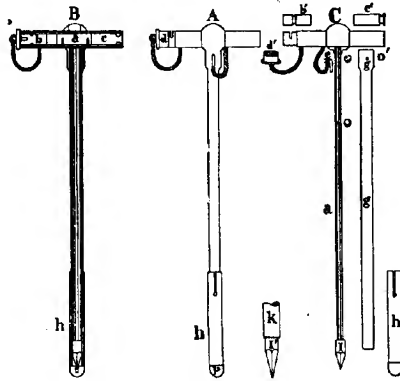


Fig. 10.

dle, is fixed a wooden plug a, which leaves two compartments, one in each end for holding the brass plug b', and the wicker lubricating wad c'. The stem of the auger a, is heavy and made of eight-sided steel and the under end is strengthened with a heavy casting fitting into the auger guide g g. The end of the auger I I' is triangular and hardened. The auger guide g g, is made out of a single piece of drawn steel tubing. Above it is strengthened by a ring-shaped piece of iron or copper and its lower end is furnished with saw teeth as shown in K and is hardened. The fixing key e, is bent in the form of a hook and can be passed through the two holes o o, of the auger stem and through the one hole o' in the strengthened part of the auger guide. It permits the auger guide to be fixed upon the auger stem in two different positions, higher and lower. On one end it is cut squarely across and on the other provided with a conical hole drilled into it. It fits on the one hand exactly in the auger guide and on the other loosely plays in the

⁶³ Deutsche landwirtschaftliche Presse, 19, No. 35, 383-4.

cavity of the handle at b, designed to hold it when not in use. The cap d' is made of heavy sheet brass and is fastened upon the end of the handle after the manner of a bayonet. The wicker cartridge is made of rolled and sewed wicker-work. At the upper end it is provided with a metallic button and before use it is saturated with paraffin oil. It fits on the one side firmly in the auger guide and on the other in the cavity of the handle c where it is kept when not in use. The union h is made of a brass tube which below is closed with a piece of solid brass upon the inside of which a hole is bored. In this hole rests the end of the auger stem when the union is placed firmly upon the auger guide.

The auger is placed together as is shown in A B, the union h is taken off and it is driven with gentle blows, turning it back and forth, to the proper depth into the soil. After the key is loosened the auger is lifted high enough so that the second hole appears and then it is fixed in position by the key. Then the boring is continued, turning the auger to the right, by which the auger, eating its way with its saw teeth, presses deeper into the ground and withdraws the material for analysis. After the auger guide has been filled through any desired length, say from five to ten centimeters with the sample of soil, the whole auger is drawn out of the soil, the key removed, the auger stem withdrawn from the auger guide, the apparatus opened by turning the bayonet fastening of the stopper on the handle, the brass plug placed in the end and then with the smooth part forward, from above, it is allowed to fall into the auger guide until it reaches the soil. The auger stem is then put back, the point of it fitting into the hole of the plug and the sample of soil shoved out of the auger guide. The auger guide is again fixed on the auger stem by the key and then the apparatus is ready for a second operation. When the borings cease the wicker cartridge is drawn out of the handle and shoved, the soft end forward, from above, into the auger guide and the brass plug after it and pushed through with the auger stem. By this process the wicker cartridge gives up a sufficient amount of paraffin oil to completely grease the inside of the auger guide and to protect it from rust. After use the instrument should be cleaned on the outside by means of a cloth, the plug and wicker wad replaced in

their proper positions, the cap fixed on the handle and the union on the point of the instrument.

The length of the whole apparatus may reach one meter or more; the internal diameter 16 millimeters. The apparatus weighs with a length of one meter, together with all its belongings, about two kilograms. For the investigation of peat and muck soils as well as sand, instead of the steel auger guide one of brass or copper can be used. For this purpose the length of the apparatus may reach three or four meters.

In comparison with other apparatus which are used for sampling, it appears without doubt that with the one just described a better and less mixed portion of the soil can be obtained at great depths. The apparatus is said to have many advantages over a similar one known as Fraenkel's, and is much more easy to clean. The advantages of the apparatus are said to be the following: The farmer with this piece of apparatus in a short time can go over his whole farm sampling to the depth of 90 centimeters since a single boring does not take more than one minute. Geologists and others interested in the soil at greater depths can use an apparatus from three to four meters in length and obtain unmixed samples from these lower depths. These are also interesting from a bacteriologic point of view. The entire apparatus is especially valuable for the investigation of the lower parts of peat and muck soils. The apparatus has been tried in the collection of samples for the laboratory of the Department of Agriculture but it is too complicated to be recommended for ordinary use. When however samples are required from considerable depths as in peaty soils it is highly satisfactory.

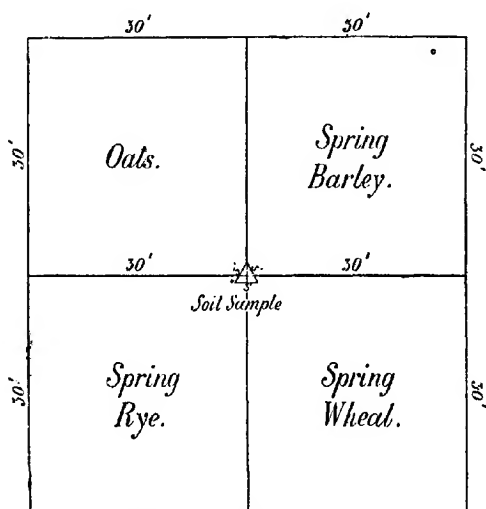
85. Sampling in Relation to Special Crop.—The special study of soils in relation to plot culture requires a special selection of samples. A method designed to meet this requirement has been devised by Moore.⁶⁶

The chief purpose of securing the samples in the manner about to be described is to study the relation between the quantities of certain plant foods in the soil, for example, potash and phosphoric acid, and the quantities of these substances removed by the crops.

In this work it is convenient to select a part of the field appar-

⁶⁶ Circular No. 9, Bureau of Chemistry.

ently homogeneous in composition 60 feet square and divide it into four parts which may be planted with the crops indicated in the appended diagram. Each part of the plot contains nearly one-fiftieth of an acre.



In the center of the plot as indicated by the triangle the sample of soil is secured from an area formed by an equilateral triangle, each side of which is three feet in length. This triangle is so laid off as to have approximately one quarter of its area in each sub-plot. Inasmuch as the whole plot is practically homogeneous in composition the equal distribution of the area of the triangle is not of prime importance. The triangular form of area is convenient because it is easy to mark out when a properly prepared belt 9 feet long and marked at intervals of 3 feet, and pegs are sent to those charged with sampling soils and crops. One peg is driven in the ground at the appointed spot, the cord drawn taut, the second peg driven, the belt placed over the two pegs drawn taut and the third peg driven at the mark.

The soil is removed from this space to a depth of 9 inches, the pit cleaned and a subsoil sample to the additional depth of 9 inches secured. The whole of the material may be used for subsampling where a great many such samples are required. To this end each of the samples is sent to the laboratory and the part that passes a 2 mm sieve retained for subsampling.

86. Soil Sampling depends for its success more on the judgment and knowledge of the collector than on the method employed and the apparatus used. One skilled in the art and having correct knowledge of the purpose of the work will be able to get a fair sample with the simplest appliances while another with the most elaborate outfit might fail entirely in collecting anything of representative value.

There are some special kinds of soil sampling, however, which cannot be left to the judgment of the individual and it is believed that with the descriptions given above nearly all purposes for which samples are desired may be served.

For the study of nitrifying organisms, however, special precautions are required and these will be noted in part eighth.

For the general physical and chemical analytical work the standard methods of sampling are all essentially the same. The principles laid down by Hilgard will be found a sufficient guide in most cases.

TREATMENT OF SAMPLE IN THE LABORATORY

87. The Sample, or mixed sample, secured by one of the methods above described, is placed on a hard smooth surface, broken up by gentle pressure into as fine particles as possible and all pieces of stone and gravel carefully removed and weighed. All roots, particles of vegetable matter, worms, etc., are also to be weighed and thrown out. The separation can be facilitated by using a sieve of from one to two millimeters mesh. Care should be taken that all the fine soil be made to pass through, which can be accomplished by subjecting the lumps to renewed gentle pressure with a rubber-tipped pestle. In the above operation the soil

should be dry enough to prevent sticking. The relative weights of the pebbles, roots, etc., and the soil should be determined.

88. Order of Preliminary Examination.—Hilgard commences the examination of a soil sample by washing about ten grams of it into a beaker with a water current of definite velocity, stirring meanwhile actively the part carried into the vessel.⁶⁷ The residue not carried by the current is examined macro- and microscopically to determine the minerals which may be present, and the condition in which the fragments exist, whether sharp or rounded edges, etc.

This examination will give some general idea of the parent rocks from which the sample has been derived and of the distance the particles have been transported. Next follows the hand test, *viz.*, rubbing the soil between the thumb and fingers first in the dry state and afterwards kneading it with water and observing its plasticity. Following this should come a test of the relations of the sample to water, *viz.*, its capacity for absorbing and retaining moisture. Finally the separation of the soil into particles of definite hydraulic value and a chemical examination of the different classes of soil particles conclude the preliminary analytical work.

89. Air-Drying.—The sifted soil should be thoroughly mixed and about one kilogram spread thinly and left for several days exposed in a room with free circulation of air and without artificial heat. The part of the sample to be used for the determination of nitrates should be dried more quickly as described in another place. The sample is then placed in a clean, dry bottle, corked, sealed, and labeled. The label or note book should indicate the locality where the sample was secured, the kind of soil, the number of places sampled, and other information necessary to proper description and identification.

90. The treatment described by Caldwell requires that the stones and larger pebbles should be separated from the finer parts by hand, or by sifting with a very coarse sieve, and examined with reference to their mineralogical character, weight and size, making note, in this last respect, of the number that are as large as

⁶⁷ Journal of the American Chemical Society, 16 : 36.

the fist or larger, the number as large as an egg, a walnut, hazelnut, and pea, or give the percentage of each by weight.⁶⁸

Pulverize the air-dried soil in a mortar with a wooden pestle, and separate the fine earth by a sieve with meshes three millimeters wide. This sieve should have a tightly fitting cover of sheepskin stretched over a hoop, and it should be covered in the same manner underneath, so that no dust can escape during the process of sifting.

Wash the pebbles and vegetable fibers remaining on the sieve with water, dry and weigh the residue; the water with which this gravel is washed should be evaporated to dryness at a temperature not exceeding 50° towards the close of the evaporation, and the residue mixed with what passed through the dry sieve.

The sifted fine earth is reserved for all the processes herein-after described, and is kept in well-stoppered bottles, marked air-dried fine earth.

91. Wolff directs that the air-dried earth(in summer dried in thin layers at room temperature, in winter in ovens at from 30° to 50°) be freed from all stones, the latter washed, dried, and weighed.⁶⁹ The soil is next passed through a three millimeter mesh sieve, the residual pebbles and fiber washed, dried, and weighed. The fine earth passing the sieve is used for all subsequent examinations. It is air-dried at moderate temperatures and preserved in stoppered glass vessels.

92. The French Commission calls especial attention to the method of subsampling, and prescribes that the sample of earth which has been secured in the manner indicated, and of which the weight should be greater as the material is less homogeneous should not be analyzed as a whole.⁷⁰ It should be divided into two parts. The first includes the finer particles constituting the earth, properly so-called, with the elements which alone enter into play in vegetable nutrition and on which it is necessary to carry out the analysis. The second embraces the coarser particles to which only a superficial examination should be given and which may have

⁶⁸ Agricultural Chemical Analysis, 168.

⁶⁹ Zeitschrift für Analytische Chemie, 8 : 87, et seq.

⁷⁰ Annales de la science agronomiques, 8th year, 1 : 247.

a certain importance from a physical point of view but which cannot take any part from a chemical point of view, in the nutrition of plants. It is, however, useful to examine its mineralogical constitution and to look for the useful elements such as lime, potash, etc., which it may be able to furnish to the earth, and in proportion as it is decomposed, finer particles which may be useful in plant nutrition.

What is the best way to distinguish between the fine and coarse elements? All grades of fineness are observed in the soil from the particles of hydrated silica so small that with the largest magnifying power of the microscope it is scarcely possible to distinguish them, up to grains of sand which are of palpable size and visible to the naked eye, and extending to pebbles of varying sizes. All intermediate stages are found between these and if it should be asked what is the precise limit at which it is necessary to stop in distinguishing the fine from the coarse elements of the soil, the answer is that this can only be determined by a common understanding among analysts. In general, it may be said, that the mark of distinction should be the separation which can be secured with a sieve having ten meshes per centimeter.

93. **Deherain** advises that the pebbles be separated by means of a sieve of ten threads, each one millimeter in diameter, to the centimeter.⁷¹ At the first shaking a part of the fine earth is separated but a part still remains on the sieve in the shape of small agglomerated masses. These are broken up in a mortar with light trituration, not breaking the pebbles. The pestled particles are again thrown on the sieve and the operation continued until the fine earth is separated. The residual pebbles are weighed and the weight of the fine earth determined by subtraction from the original weight of the sample. The pebbles are treated with hydrochloric acid to determine whether they are calcareous or silicious in character.

94. **Loose Soils.**—Having selected a sieve of given size, the process of separation in loose soils is as follows: The earth is exposed to the air and when the touch shows that it is sufficiently dry the conglomerated particles should be simply divided without breaking the rocky material which exists in a state of undivided

⁷¹ *Chimie Agricole*, Second edition, 1902, 396.

fragments. There are some special precautions to be taken. Rubbing in a mortar must be forbidden since it reduces the earth to particles which are unnatural in size, as a result of the breaking up of the fragments consisting of the débris of rocks. When it is possible the earth should be rubbed simply in the hand and after having separated that which passes the sieve, the large particles which have not passed should be again rubbed with the hand, until all the particles which can be loosened by this simple treatment have passed the sieve. The separation should be complete in order that a sample of the particles passing the sieve should represent as nearly as possible, a correct sample of the fine particles of the soil.

In regard to the pebbles, they should be washed with water upon the sieve in order to carry through the last of the particles of earth adhering to them. They are then dried and their weight taken. The fine part of the earth is also weighed. On an aliquot part, say 100 grams, the moisture is determined and then the weight of the whole sample of the air-dry soil can be calculated to the dry state. The sample is then placed in a glass flask.

The pebbles are examined with a view of determining their mineralogical constitution; as for instance, on being touched with a little hydrochloric acid it can be determined whether or not they are carbonate of lime. The nature of the rock from which they have been derived is often to be determined by a simple inspection.

95. Compact Soils.—If the soils are not sufficiently loose to be treated as before described, it is necessary to have recourse to other means of division which should not, however, be sufficiently energetic to reduce the rocky elements to fine particles. For this purpose the earth may be broken by means of a wooden mallet, striking it lightly and separating the fine elements from time to time by sifting. A wooden roller may also be used with a little pressure for breaking up the particles, or a roller made out of a large glass bottle. These methods will permit of a sufficiently fine division of the soil without breaking up any of the pebbles. Sometimes, however, a soil can not be broken up by such treatment. It is then necessary to have recourse to the following process: The soil is thoroughly moistened and afterwards rubbed up with water. The paste which is thus formed, is poured upon the sieve

and washed with a stream of water until all the fine particles are removed. The wash water and the fine particles are left standing until the silt is thoroughly deposited when the supernatant water is poured off and the deposited moist earth is transferred into a large dish and dried on a sand or water-bath. In this way a firm paste is formed which can be worked up with the hand until rendered homogeneous and afterwards an aliquot portion be taken to determine moisture.

96. Method of Peligot.—The method recommended by Peligot for the preparatory treatment of the sample is essentially that already described.⁷² The sample is at first dried in the air and then in an oven at 40°. When dry and friable 100 grams are placed in a mortar and rubbed with a wooden pestle. It is then passed through a sieve of 10 meshes per centimeter. The stones are separated by hand. They should be shaken with water in order to detach any pulverulent particles adhering thereto. The turbid water resulting from this treatment is added to that which is used in separating the sand from the impalpable part of the soil.

97. Wahnschaffe prescribes in the further preparation of the sample for analysis that the coarse pieces up to the size of a walnut be separated in the field where the sample is secured and their relative weight and mineralogical character determined.⁷³ The soil sample is then to be placed in linen or strong paper bags and carefully labelled. In order to avoid any danger of loss of label the description or number of the sample should be put on the cloth or paper directly.

The sample when brought to the laboratory should be spread out to dry, in a room free of dust. In the winter the room should be heated to the usual temperature. The air drying should continue until there is no sensible loss of weight. The samples then are to be placed in dry, glass-stoppered bottles where they are kept until ready for examination. This method of keeping the samples avoids contact with ammonia or acid fumes with which a laboratory is often contaminated.

98. The Swedish chemists direct that samples which are to be used for chemical examination in the manner described below, are

⁷² *Traité de Chimie analytique appliqué à l'Agriculture*, 149.

⁷³ *Anleitung zur wissenschaftlichen Bodenuntersuchung*, 19.

most conveniently brought to such a condition of looseness and humidity that the soil feels moist when pressed between the fingers without, however, sticking to the skin.⁷⁴ To prepare the sample in this manner, spread it in a large porcelain dish or on a glass plate in a place where it is not reached by the laboratory atmosphere; stir it frequently till it assumes the mentioned humidity (if the sample when sent is too dry, moisten it with distilled water till its condition is as indicated); then pulverize carefully between the fingers and finally sift through a sieve with holes five millimeters in diameter. In this way free the sample from stones, undecayed roots and similar parts of plants, pieces of wood, and other matter strange to the soil, which remain on the sieve; mix the sample carefully and put it into a glass bottle provided with a stopper well ground in and keep it in a cool place. Samples prepared in this way will usually contain from 20 to 30 per cent. moisture, boggy soils from 60 to 80 per cent. and peaty soils 50 per cent.

99. **Petermann** follows the method outlined below in preparing samples of soil for analysis.⁷⁵

The soil is gently broken up by a soft pestle and all *débris*, if of organic nature, is removed by forceps, cut fine with scissors, washed free of adhering earth dried at 120° and weighed. The nature of the organic *débris* should be noted as carefully as possible. About 2500 grams of this soil are passed through a one millimeter-mesh sieve.

The pebbles and mineral *débris* not passing the sieve are washed in a large quantity of water by decantation. They are also dried at 120° and weighed. This *débris* is examined mineralogically and thus some idea of the origin of the soil obtained.

100. The various methods for the preliminary treatment of soils as practiced by the best analysts have been somewhat fully set forth in the foregoing résumé. The common object of all these procedures is to get the soil into a proper shape for further physical and chemical examination and to determine the weights of pebbles and foreign bodies contained therein.

⁷⁴ Methods of Analysis of Soils and Fertilizers adopted by the Swedish Agricultural Chemists, translated for the author by F. W. Woll.

⁷⁵ *L'Analyse du Sol*, 14.

The essential conditions to be observed are the proper sifting of the material and avoidance of mechanical comminution of the solid particles too large to pass the meshes of the sieve. If possible the material should be passed through a sieve of one millimeter mesh. In cases where this is impracticable a larger mesh may be used, but as small as will secure the necessary separation. Before final chemical analysis a half millimeter mesh sieve should be employed if the soil be of a nature which will permit its use. Overheating of the sample should be avoided. Rapid drying at temperatures not exceeding 50° is advisable when the samples are to be examined for nitrates.

The methods recommended seem well adapted to the general treatment of samples, but the analyst must be guided by circumstances in conducting the preparation of the sample in the laboratory or by the special object in view.

The analyst should always bear in mind, both in getting and preparing the samples the principal purposes to be served by the examination. The problems connected with the study of the soil are so complex that no hard and fixed rules can be applied in all cases. Much of the prejudice which is prevalent regarding the physical and chemical study of soils is due to the lack of care in selecting and preparing samples. It should not be forgotten that all of our exact knowledge concerning soils, their origin, character, classification and fertility, has been obtained through the media of physical and chemical study.

PART THIRD

STUDY OF PHYSICAL PROPERTIES

101. Color.—The color of a soil depends chiefly upon the proportion of organic matter and iron compounds which it contains and the state of subdivision of its particles. When a soil contains a large amount of organic matter, especially when this organic matter is in an advanced state of decay, it assumes more or less a black or brown color when moist. This black color is to be distinguished from the black alkali tint which is produced by the action of carbonate of soda on organic matter. The naturally black color of a soil containing a large amount of organic matter depends either upon the action of mineral matters upon this organic matter, as in the case of the black alkali mentioned, or upon the blackish color of carbon resulting from the slow combustion of the organic matter during the period of decay.

The presence of a large amount of ferric oxid in soil gives the well-known red color so well-marked in the soils of many portions of the United States. The preponderance of sand in a soil tends to produce a light yellow or whitish tint, while certain kinds of clay have a bluish tint probably due to the presence of ferrous salts together with some organic matter. The influence of the color of the soil upon the color of the vegetation is also well-marked, the black soils as a rule producing a much deeper green tint of foliage than the light colored soils. This effect should not be attributed to color alone for as a matter of fact highly colored soils are usually very retentive of moisture. Such soils will produce a more vigorous and ranker growth of vegetation, but it is the texture of the soil, the superabundance of plant food especially nitrogen, and the more moist condition which it maintains, rather than the color, which produce the deeper green tint of foliage.

The color of a soil is also within certain limits an index of its fertility, the black and red soils being usually the most fertile.

102. Determination of Color.—There is no process which will give experimentally and accurately the color of a soil sample. The changes which the color of a soil undergoes in passing from a saturated to an anhydrous state are well-marked. The analyst will have to be content with giving as nearly as possible a description of the color of the sample when received and the changes which it undergoes in air drying or on heating in a bath to 100°-110°, or in heating to redness with or without exclusion of the air. These changes in color will give some indication of the character of the organic and mineral matters present. Since the content of water influences so greatly the apparent color it is advisable to reduce all samples to the same condition of moisture for comparative purposes. There are two conditions which are easily attained, *viz.*, air-dried and saturated. Comparison of colors should be made in each of these states.

103. Odoriferous Matters in Soil.—It is known that the soil emits a peculiar odor which is not disagreeable and which is most intense when it has been recently wet, for instance, after a short rain. Several attempts have been made to discover the nature of this odor. These researches have established the fact that the essential principle of this odor resides in an organic compound of a neutral nature of the aromatic family and which is carried by the vapor of water after the manner of a body possessing a feeble tension. The odor is penetrating, almost piquant, and analogous to that of camphorated bodies and quite distinct from other known substances. In regard to the quantity of this substance, it is extremely minute and can be regarded as being only a few millionths of a per cent.

According to Berthelot and André⁷⁸ this new principle is neither an acid nor an alkali nor even a normal aldehyd. It is, in a concentrated aqueous solution, precipitable by potassium carbonate with the production of a resinous substance. Heated with potash it develops a sharp odor of a resinous character. It does not reduce the ammoniacal nitrate of silver. Treated with potash and iodine it gives an abundant formation of iodoform, which, however, is a property common to a great number of substapces. These authorities have not found in the emanations from moist

⁷⁸ Comptes rendus, 122 : 598.

soil either furfural, acetone or alcohol said by Müntz to exist in certain soils where moreover their existence is easily explained. They do not appear to occur generally.

For the qualitative and quantitative estimation of the odoriferous matter the following process is employed: About three kilograms of the soil, mixed with the sand containing a small amount of carbonate of lime and some humic substance characteristic of the soil of Meudon are used for the determination. After having freed it from all organic debris which is visible, it is placed in a glass alembic. The soil should contain from 10 to 12 per cent. of water at least. The alembic is placed in a sand bath and is kept at 60° for several hours. The evaporated water is condensed until about 175 cubic centimeters are distilled over. This distilled water is again rectified so as to obtain in all about 20 cubic centimeters. The odoriferous matter appears to be nearly all contained in this 20 cubic centimeters, showing its feeble vapor tension. The liquid thus obtained shows an alkaline reaction; it contains some ammonia and reduces ammoniacal silver nitrate. This last reaction is due to some pyridic alkali or analogue thereof, since when it is distilled anew with a trace of sulfuric acid it gives a neutral liquor deprived of all reducing action but which preserves the odor peculiar to the soil. The 20 cubic centimeters obtained as before are subjected to two additional distillations and in the final one only one cubic centimeter of liquid is distilled over. The peculiar odor is intensified proportionately as the volume of the liquid is decreased. To this one cubic centimeter, is added some pure crystallized potassium carbonate. The liquor is immediately troubled and some hours are required for it to become clear again. Meanwhile there is formed upon its surface a resinous ring almost invisible, amounting at most to from 10 to 20 milligrams of a matter which has not been identified with any known principle. The reactions described above, however, permit of its general character being known. This resinous matter contains the odoriferous principle, the composition of which is not yet definitely known.

104. Specific Gravity.—The density of a soil depends on its composition, the fineness of its particles and upon the packing which

it has received. It has in other words an apparent and a real specific gravity. It is easy to see that a soil in good tilth would weigh less per cubic foot than one which had been pressed closely together, as in a road or well-grazed field. Ordinary soils in good tilth have an apparent specific gravity of about 1.2, and when entirely free from air, a real specific gravity of about 2.5. If the apparent specific gravity of a soil sample were 1.2 and the air were removed, leaving a vacuum in the interstices of the soil, the apparent specific gravity would not be sensibly increased. The figure 1.2 is the apparent specific gravity of a mixture of soil material which is about $2\frac{1}{2}$ times heavier than water, and of an extremely small proportion by weight of air which is about 1000 times lighter than water. The figure 2.5 is about the true specific gravity of the real soil material, except in soils containing an excessive amount of organic matter.

The weights of a cubic foot of different kinds of soil as given by Schübler⁷⁷ are as follows:

	Pounds.
Sand.....	110
Sand and clay.....	96
Common arable soil.....	80 to 90
Heavy clay.....	75
Vegetable mold.....	78
Peat.....	30 to 50

In general the specific gravity of soil decreases inversely as its content of humus.

105. Determination of Specific Gravity.—The ordinary method of proceeding to determine the true specific gravity is by means of a pyknometer. The pyknometer should have a capacity of from 25 to 50 cubic centimeters.

From 10 to 15 grams of earth dried to constant weight at 100° boiled for a time with a few cubic centimeters of water to remove air are poured into the pyknometer. All soil particles are washed out of the vessel in which the boiling takes place into the pyknometer with freshly boiled distilled water and after cooling to the temperature of the calibration of the pyknometer it is filled with distilled water at the given temperature and weighed. If the soil contain materials soluble in water in any

⁷⁷ Stockbridge: *Rocks and Soils*, 153.

proportion large enough to influence the results, alcohol of definitely known specific gravity may be employed and the number thus obtained calculated to a water basis.

The calculations when water is used are made as indicated in the following example:

	Grams.
Weight of pyknometer	13.4789
“ “ “ full of distilled water at 20°	62.8934
“ “ water in pyknometer	49.4145
“ “ dry soil	10.0000
“ “ pyknometer + dry soil + filled with water at 20°	67.9834
“ “ soil and water	54.5045
“ “ water	44.5045
“ “ “ displaced by ten grams soil	4.9100

Then specific gravity = $10.000 \div 4.9100 = 2.0367$.

106. Specific Gravity of Undried Soils.—It is often desirable to determine the specific gravity on an undried portion of the soil. For this purpose a portion of the sample is dried at 100° to determine its percentage of moisture. The specific gravity is then determined on a 10 gram sample of the undried soil as just given. The actual weight of soil is calculated from the percentage of moisture obtained in the first instance. In the case given if the percentage of moisture at 100° is found to be 10 then the actual weight of dry soil is nine grams. This number is therefore used in making the calculations. In all statements of specific gravity determined in the manner described the temperature at which the pyknometer is calibrated should be stated and all weighings where water is involved made at that degree. If it is desired to refer the specific gravity made in the manner above described to any other temperature of water as for instance 4° it is easily accomplished by a simple calculation.

107. Volume of Soil.—If it be desired to calculate the volume occupied by a soil it is easily done by dividing the weight of water displaced by the weight of one cubic centimeter of water of the temperature at which the determination took place.

In the case given one cubic centimeter of water at 20° weighs 0.998259. Then $4.9100 \div 0.998259 = 4.9186$ cubic centimeters = volume occupied by 10 grams of dry soil excluding interstitial spaces between particles. The actual volume including intersti-

tial spaces occupied by a finely divided mineral substance such as the fine earth used in soil analysis is larger when in a dry state than when saturated with water. This may be shown by grinding a rock to a fine powder and placing the dust in a graduated cylinder, and shaking the cylinder to constant volume. The same volume of the dust when thoroughly saturated with water will be found to occupy a smaller volume. The fine soil therefore tends to become more compact when wet than when partially dry.

108. Volumetric Methods.—The water displaced by a given weight of soil may also be measured volumetrically by the method of Knop⁷⁸ slightly modified to secure greater simplicity.

Place 200 grams of the dry soil in a flask of 500 cubic centimeters capacity. Add a measured quantity of water, and shake thoroughly to eliminate air, and fill up to the mark from a burette. The quantity of water required to complete the volume subtracted from the number expressing the volume of the flask will give the volume of water displaced by the earth.

Another method consists in thoroughly shaking about thirty grams of the soil in a graduated cylinder with 50 cubic centimeters of water containing a little ammonium chlorid and after 24 hours recording the volume occupied by the whole. The increase in volume over 50 cubic centimeters shows the quantity of water displaced. This method may also be used to determine the volume occupied by a soil when saturated with water. The above methods are only to be used when approximately correct results are all that are desired.

109. Apparent Specific Gravity.—The apparent specific gravity of a soil is obtained by dividing its volume, interstitial spaces included, by the weight of an equal volume of water.

The real and apparent specific gravities of six samples of soil are given below:⁷⁹

	1.	2.	3.	4.	5.	6.
Real specific gravity.....	2.5445,	2.6315,	2.6508,	2.6400,	2.7325,	2.6603
Apparent specific gravity						
of air dried soil	1.0940,	1.1710,	1.3570,	1.2810,	1.4060,	1.2735
Apparent specific gravity						
of soil dried at 125°.....	1.0990,	1.1770,	1.3750,	1.2910,	1.4640,	1.2800

⁷⁸ Die Landwirtschaftlichen Versuchs-Stationen, 8 : 40.

⁷⁹ König, Landwirtschaftlich und Gewerblich Wichtige Stoffe, 2d Edition, 47.

It is to be noted that in computing the apparent specific gravity of a soil dried at 125° the volume occupied by the water is assumed to occupy the same space as if it existed in a free state. The volume of this water is therefore to be subtracted from the contents of the flask before proceeding with the computations.

110. Determination of Weight per Hectare or Acre.—Place in small quantity at a time portions of the air-dried sample properly prepared in an open cylinder, holding one liter, and about 170 millimeters high (if the height is exactly the mentioned one, the diameter of the cylinder will be 86.6 millimeters); pack the sample by striking the bottom of the cylinder hard against the palm of the hand after each new filling and weigh on a balance sensitive to 0.1 gram. The weight of one liter of soil in approximately similar conditions as it is found on the dry land prepared for cultivation, is thus ascertained. The weight of one liter of the soil in grams multiplied by 2000 will give in kilograms the weight of the surface soil from a hectare (2.47 acres) of the field from which the sample is taken to the depth of 20 centimeters.⁸⁰

RELATION OF THE SOIL TO HEAT

III. Sources of Soil Heat.—The heat of the soil comes from three sources, *viz.*: solar heat, heat of chemical action within the soil, and the original heat of the earth's interior. The latter is sensibly a constant quantity, and of great value to plants. The heat of chemical action is not great in amount except in a few special cases but is often, as in germination, of the greatest importance to plant growth. The sun, therefore, remains the greatest source of heat of practical importance in relation to the production of crops. Dark-colored soils, absorbing most and radiating the fewest rays, must attain the highest temperature. Schübler's classical researches on soil temperatures, show that there is at times a difference of over 7° in temperature between white and black soils, all other conditions being alike. Schübler's researches, made on dry soils in the laboratory, are not to be applied too rigidly to conditions in the field.

⁸⁰ Methods of the Swedish Agricultural Chemists, translated for the author by F. W. Woll.

112. Influence of Specific Heat.—The quantity of heat which a soil receives and retains is determined in given conditions by its specific capacity for heat. The specific heat of a body is expressed by a number which shows the amount of heat necessary to raise a given weight of the body 1° of temperature, as compared with the amount necessary to raise the same weight of water 1° . The specific heat of the soil is usually between 0.20 and 0.25 when that of water taken as the standard is unity.

113. Influence of Moisture.—The moisture of the soil possesses great influence on the soil temperature, so much so that a dry, light-colored soil may attain a greater degree of warmth than a moist, dark-colored one. The wetter the soil the larger the quantity of heat required to raise the temperature to any given degree. The action of water in reducing soil temperature is easily explained. In our latitude, we see the water in all its forms, solid, liquid, and gaseous, and we know that these forms are the direct result of temperature. The changing of water from the solid to the liquid or gaseous form is performed at the expense of heat; the more water evaporated from the soil the more heat must be used for the evaporation. Therefore, the more water contained in the soil at any given time the lower must be its temperature during subsequent exposure to sun heat because of the greater evaporation. The experiments of many careful investigators have practically settled all the important questions of soil temperature. The radiation of heat from the soil, and the consequent cooling propensity of the latter, are directly proportional to the absorptive power of the soil. Two soils of like absorptive power towards heat possess, as a rule, equal radiating power.

In a general way, it can be said the greater the heating capacity and conductivity of a soil the more readily and rapidly does it give off its heat and become cooled.

114. Absorption of Solar Heat.—The quantity of heat absorbed from the sun by the earth is an important factor in the growth of vegetation. As has been established in the physics of heat, a black surface, other things being equal, will absorb a larger amount of heat than one of any other color; so, other things being equal in the physical and chemical composition of a soil, variations in the amount of organic matter producing greater or less black color-

ation will affect the heat absorption. Thus, black soils, in the conditions above mentioned, will absorb more heat than lighter colored soils. As a result, the vegetation in such soils gets an earlier start in the Spring and matures more rapidly. As an illustration of this it may be noted that the black prairie soils of Iowa produce uniformly crops of maize which are matured before the early frosts, while crops grown on lighter soils much farther south often suffer injury from that source.

DETERMINATION OF SPECIFIC HEAT

115. General Principles.—The quantity of heat stored in any given weight of soil is capable of being measured and compared with the quantity stored in an equal weight of water at the same temperature. The ease, however, with which disturbing influences operate during the determination makes the manipulation somewhat difficult. The specific heat of the containing vessels must be carefully determined. Fortunately this has been done for most materials and the data thus obtained are recorded in standard works on physics. The material operated on must be protected from thermal influences from sources not controlled by the experiment and even the heat of the operator's body may often disturb the conduct of the work. The general conditions which should control the experiment as well as the details thereof are given in the following method which, however, the ingenious analyst may profitably simplify.

116. Method of Pfaundler.—The process of estimating the specific heat of soils by the method of mixture, is essentially that of Regnault and is described as follows by Pfaundler.²¹

The apparatus used is illustrated in Fig. 11.

A and A₁ show the heating apparatus. It consists of a vessel of sheet iron in which a test tube E is fixed by means of a cork. The test tube holds the soil whose specific heat is to be determined. The apparatus contains water, which is brought to the boiling point by means of a lamp, and the excess of steam is conducted away, as indicated in the figure, through one of the axes of the apparatus; the opposite axis is, of course, closed. It requires

²¹ Poggenдорfs *Annalen der Physik und Chemie*, 1866, [5] 9 : (128), 102, et seq.

about 35 minutes boiling to bring the contents of the test tube to the temperature of the aqueous vapor. To avoid the effect of radiation the apparatus above the water line should be covered with cotton or some other non-conductor of heat. The exact temperature at which the water boils is determined by observing the barometer at the time and consulting a table of the boiling temperature of water at different barometric pressures.

The calorimeter is shown in the figures B and B₁. It consists of a wooden box closed on one side by a glass plate G and on the other to the height F by a small board on which a calorimeter of ordinary construction is placed. The inner thin-walled cylinder of the calorimeter is 70 millimeters high and 47 millimeters in diameter. The outer envelope of the calorimeter is correspondingly wider and deeper.

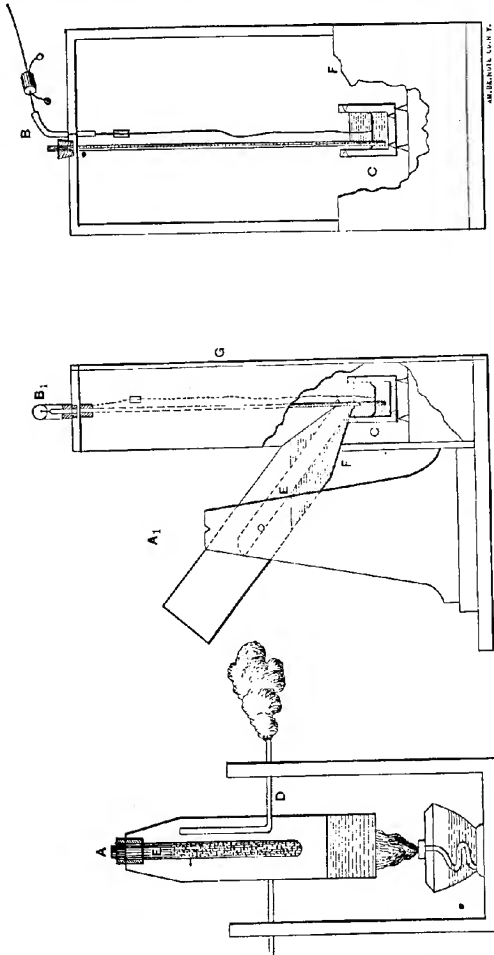
Both parts of the apparatus are supported by triangular pieces of cork. A delicate thermometer is fastened to the top of the box of the calorimeter and the value of the degrees is so arranged that about twelve of them correspond to about one degree C. The scale of the instrument can be arbitrarily fixed and the temperature of any part of it determined by comparison with a delicately graduated thermometer.

Near the thermometer in the calorimeter is a perforated stirrer made of a very thin copper disk with a bent rim. This stirrer is operated by means of a silk cord moved by appropriate machinery. The advantages of the apparatus over Regnault's consists in having the calorimeter stationary and in the facility with which the heated sample can be introduced into the calorimeter so as not to sensibly influence the results by any heat that might come therefrom.

The reading of the thermometer is made through a glass plate and this should be protected from the heat of the body of the observer by a paper screen.

The test tube E is first filled with the substance, whose specific heat is to be determined, and weighed. It is then placed in the water bath until constant weight is reached. After constant weight has been obtained the apparatus is again weighed and the exact weight of the moisture lost thus determined. The test tube is then placed in the apparatus A closed with a well-fitted cork,

the top covered with cotton and heated in the aqueous vapor for



about one hour. The heating apparatus should be far removed

from the calorimeter and screened so that the temperature of the latter cannot be influenced thereby. Meanwhile the calorimeter is filled with water which has stood in the room for a long time until it has acquired, as nearly as possible, the room temperature.

The quantity of water is such that the water value of the whole of the calorimeter together with the immersed portions of the thermometer and stirrer shall amount to exactly 100 grams of pure water. A few minutes before bringing the substance into the calorimeter, the stirring apparatus is put in motion and the temperature observations are commenced. These should be at intervals of 20 seconds and should be continued until 10 observations have been made. Meanwhile the height of the barometer is also read. A few seconds before the tenth interval the apparatus A is brought quickly to the calorimeter and its contents emptied into it at the moment of the tenth interval. The apparatus A should be removed as quickly as possible after its contents are emptied.

After the introduction of the substance and its thorough incorporation with the water of the calorimeter by the stirring apparatus, the thermometer is again read, at intervals of 20 seconds, until its maximum has been reached and as much longer thereafter as may be necessary to show that an appreciable fall of temperature has taken place. The test tube, in which the substance was heated is weighed and the exact quantity of the added substance thus determined. In inverting the test tube to deliver the heated soil to the calorimeter care is taken that no part of the apparatus A touches any part of the calorimeter. To aid in this a cork shield should be fixed on the board F at a convenient height.

In order that the sample of soil may be easily removed from the test tube in which it is heated, it is best to have it molded into appropriate forms before being placed in the heating tube. This is easily accomplished by pressing it into molds of convenient shape and of a size so that six or eight pieces (best of cylindrical shape) will be necessary to give the quantity sufficient for the experiment. Since some soils will not retain their shape after molding, the molds may be made of zinc foil whose water values in the calorimeter are previously determined and they can be placed with their contents in the calorimeter thus securing the

total immersion of all the particles of soil in the water. This is important with certain soils rich in humus and with peats which in a dry state will not sink unless thus weighted. With very dusty materials, it is necessary that these little cylinders should be closed with pieces of foil at the ends in order to prevent the particles of dust from escaping and rising to the surface of the water. The greatest care should be taken to avoid splashing the water in the addition of the tablets of soils. It is sometimes advisable to remove the test tube from the rest of apparatus A and manipulate it by hand.

Another source of error consists in the solution of the soluble salts which the soil may contain. This is avoided by the use of turpentine instead of water. If the cylinder containing the soil be made water-tight, this danger from the solubility of the salts in water is avoided. Another method of correcting these errors is in making a blank experiment in which a quantity of the earth taken is kept at the temperature of the water in the calorimeter until both are of the same temperature. The earth is then mixed with the water and the change of temperature produced noted. In this way the corrections made necessary by the solution of the salts in water and other causes are determined.

117. Method of Calculating Results.—Let t represent the mean temperature of the beginning period of the experiment, and v equal the loss in heat per interval. Let t' and v' represent the same values for the end period. Let $\theta_1, \theta_2, \theta_3$, etc., represent the temperature at the end of the first, second and third intervals of the middle period and θ_n the temperature at the beginning of the middle period and θ_n the end temperature of the middle period. Let $\tau_1, \tau_2, \tau_3, \dots, \tau_n$ represent the mean temperatures of the single intervals; then $\tau_1 = \frac{\theta_0 + \theta_1}{2}$; $\tau_2 = \frac{\theta_1 + \theta_2}{2}$, and $\tau_n = \frac{\theta_{n-1} + \theta_n}{2}$. C represents the correction which must be applied in order to determine the true increase of temperature in the calorimetric system. The expression $\theta_n - \theta_0 + C$ represents the true temperature increase of the calorimetric system which we may represent by $\Delta\theta$, and $\theta_n + C$

represents the true maximum, that is, the end temperature, which by exclusion of external influences is reached. The correction C , as already indicated, is to be added to $\theta_n - \theta_0$ when it is positive and is to be subtracted therefrom when it is negative. The numerical value of C is usually very small, and, in the experiments indicated, varies between zero and one division of the thermometer employed, and seldom reaches two divisions. Let v = the mean loss of temperature per interval in the first period and v' the same for the end period.

Then the value of C may be computed according to the following formula:

$$C = nv + \frac{v' - v}{t' - t} \left[\theta_1 + \theta_2 + \theta_3 + \dots + \theta_{n-1} + \frac{\theta_1 + \theta_n}{2} - nt \right]$$

from which

$$C = nv + \frac{v' - v}{t' - t} \left(\sum_{n-1} \theta + \frac{\theta_0 + \theta_n}{2} - nt \right)$$

118. Illustration.—This method of determining the value of specific heat is best illustrated by an example:

In one determination the water value of the calorimetric system, including stirrer and thermometer was 2.50 grams, the weight of water added was 97.50 grams and the total water value of the system 100 grams. The substance was dried at 100° and weighed in five envelopes:

Total weight	31.423 grams
The envelopes alone weighed.....	10.654 "
Weight of soil	20.769 "

The envelopes holding the soil were made of brass, the specific heat of which is 0.0939 and the water value of the whole of the envelopes was 1.0004 grams. Since, however, the ends were soldered on with tin the true water value was somewhat smaller being equal to 0.8692 gram. The data of the observations were as follows:

Corrected height of barometer.....	699.6 millimeters.
Intervals between the observations	20 seconds.

	No. of Observations.	Temperature on the arbitrary scale of the thermometer.	
First Period {	0	162°.6	
	10	162°.9 = θ_0 (Moment of immersion).	
	11	185°.0	
	12	200°.0	
	13	206°.1	
	14	209°.5	
	15	210°.7	
Second Period {	16	211°.3	Differences.
	17	211°.5	0
	18	211°.5	0
	19	211°.5	0
	20	211°.5	0
	21	211°.5	-0°.1
	22	211°.4 = θ_n	
	23	211°.3	-0°.1
	24	211°.2	-0°.1
	25	211°.1	-0°.1
Third Period {	26	211°.0	-0°.1
	27	210°.9	-0°.1
	28	210°.8	-0°.1
	29	210°.6	-0°.2
	30	210°.5	-0°.1

From the twenty-second interval, the regular fall of temperature begins and 211°.4 is therefore taken as θ_n . The mean temperature of the beginning period is therefore $\frac{162°.6 + 162°.9}{2}$

= 162°.75 = t . The value of v is $\frac{162°.6 - 162°.9}{10} = -0°.03$.

For the end period the value of t' is $\frac{211°.4 + 210°.5}{2} = 210°.95$

and the value of v' is $\frac{211°.4 - 210°.5}{8} = +0°.11$. Then the sum of the observations from 11 to 21 inclusive = $\Sigma'_{n-1} \theta \dots 2280.1$.

$\frac{\theta_0 + \theta_n}{2} =$	187.15
The sum =	2467.25
$n = 12$	
$nt =$	1953.00
Difference	514.25
This difference multiplied by $v - v' =$	0.14
gives a product equal to	71.995
This product divided by $t' - t =$	48.20
gives a quotient equal to	1.49
$nv =$	-0.36
The sum =	1.13 = C

Then $\Delta\theta = \theta_x - \theta_0 + C = 211^{\circ}.4 - 162^{\circ}.9 + 1^{\circ}.13 = 49^{\circ}.63$.
 The true end temperature $= \theta_x + C = 212^{\circ}.53$. The zero point of the thermometer $= 24^{\circ}.70$, and the actual rise of temperature $= 187^{\circ}.83$. The rise of temperature due to the proximity of the warming apparatus at the beginning was found by experiment to be equal to $0^{\circ}.1$ of the division of the scale. On comparing the thermometer used with a standard centigrade scale it was found that one division of the calorimetric thermometer was equal to $0^{\circ}.0858$. Converting these numbers into expressions of the centigrade scale we have the following summary:

The true rise of temperature, $\Delta\theta =$	$4^{\circ}.25$
The true end temperature, $\theta_x + C =$	$16^{\circ}.10$
The temperature of the steam, as determined by the height of the barometer, was equal to.....	$97^{\circ}.70$

From these data the specific heat is calculated according to the following formula:

$$S = \frac{1}{20.769} \left(\frac{100 \times 4.25}{97.70 - 16.10} - 0.8692 \right) = 0.2089.$$

From this formula the following rule for calculating specific heat is deduced:

Multiply the water value of the calorimetric system by the true rise in temperature in degrees Celsius and divide the product by the difference between the temperature of boiling water under the conditions of the experiment and the true end temperature. From the quotient subtract the water value of the envelopes holding the soil sample. Divide the remainder by the weight of soil in a dry state.

119. Method of Lang.—Lang has made use of a somewhat simpler form of apparatus in securing the specific heat of soil samples.⁸²

The apparatus employed consists of a heater, made of heavy sheet iron Fig. 12 forming an air bath with double walls. The bottom forms a movable door, in which open two tubes for carrying a thermometer *c* and a gas regulator *d*. On *S* is fixed an arm carrying a hook *f* to which is attached a fine wire to support the

⁸² Forschungen auf dem Gebiete der Agricultur-Physik, 1, 109.

body to be heated and passing freely into the heating chamber at *a*. A movable wire gauze *e e* aids in regulating the temperature.

The calorimeter shown in vertical section is formed of two vessels *m* and *n* made of thin polished brass. Conduction between the inner and outer parts is prevented by wood or cork plugs at *o* and *p*, and the calorimeter is fixed to a sliding base which permits it to be brought under the air bath at the proper moment.

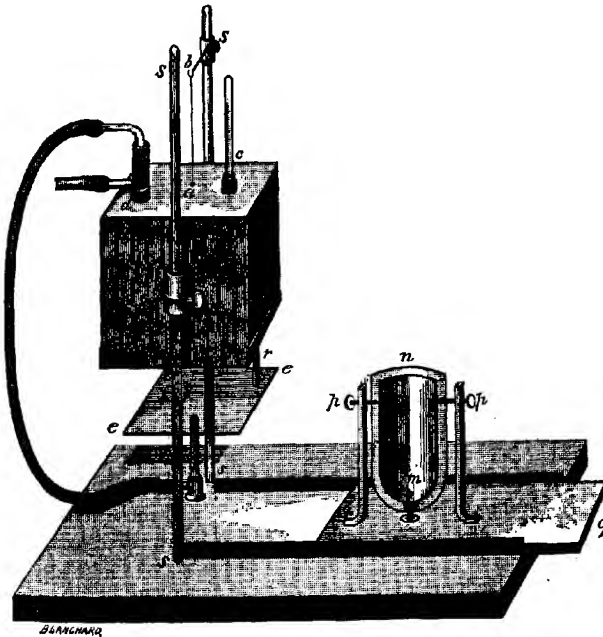


FIG. 12.

To bring the heated sample into the calorimeter the wire gauze *e e* is removed and with one hand the operator shoves the calorimeter under the air bath by which motion the movable bottom is opened by the peg *r*; with the other hand the wire holding the sample is cut allowing the sample to fall into the calorimeter. The

whole operation should not consume more than 5 seconds. The temperature of the water in the calorimeter and the water value of the whole apparatus is obtained in the manner already described. The calorimeter is covered by a perforated glass plate, not shown in the figure, previous to and after the introduction of the sample.

The samples are conveniently held in light glass-stoppered (water-tight) bottles. The heat value of the bottle* and attached wire are determined and allowance made therefor in the calculations.

The specific heat is calculated according to the following formula:

$$S = \frac{(P + p_c + p_t) (\tau - t) - p_g \cdot s' (T - \tau)}{p (T - \tau)}$$

In this formula P = weight of water in calorimeter

p = net weight of sample

p_c = water value of the calorimeter

p_t = water value of the thermometer

p_g = weight of the glass container

s' = water value of container

T = constant temperature of the air bath

t = beginning temperature of calorimeter

τ = end temperature of calorimeter

120. Variations in Specific Heat.—Different soils deport themselves very differently in respect of specific heat. In a large number of soils examined by Pfaundler, the specific heats were found to vary from 0.2081 to 0.5069. The highest specific heat was observed in the case of a peaty soil. Next to peaty soils came those soils which were highest in humus, and in general it was found that the specific heat varied directly with the humus content. The lowest specific heats are found in soils composed chiefly of sand.

SOIL THERMOMETRY

121. General Principles.—The measurement of the temperature of the soil at stated depths is often of use in analytical processes connected with agricultural chemistry and physics. The general principles on which the process rests, depend on bringing the bulb of the thermometer into as intimate contact as possible with the

particles of soil at the depth required, disturbing as little as possible the normal state of the soil particles.

In the thermometer chiefly used for this purpose in this country, the stem is strong and carries the degrees figured on the glass. The whole is enclosed in a wooden case which is cut away to expose the face of the scale. The scale is about eleven inches long. The part which enters the soil is of varying lengths, according to the depth at which the temperature is desired.

122. Method of Procedure.—An excellent method of determining soil temperatures and of recording results is well illustrated by Frear.⁸³

The thermometers are set in niches cut in a trench, the earth being afterwards carefully tamped about the bulbs to secure a good contact, the trench being filled at the same time. The surface of the soil is freed from vegetation and kept in good tilth.

The depths at which observations are made are at the surface and one, three, six, 12 and 24 inches. The soil for which the following illustrative data are given was moderately dark and loamy to a depth of seven inches and below that a stiff clay. Solid rock existed at from five to seven feet below the surface. Readings were made three times a day.

123. Method of Stating Results.—The individual readings of the thermometers should be entered at the time they are made. At the end of each month the mean of the readings should be determined, together with the maxima and minima, and a comparison made between the mean readings of the temperature of the air and maxima and minima. The determination of soil temperatures is particularly useful in their relations to germination and the early growth of plants. Often it will prove useful to determine the proper time for planting. As an illustration of the method of stating these mean results the data are given for the month of May for the atmosphere, surface, and for the depths of soil mentioned above:

⁸³ Report of the Pennsylvania State College, 1891, 194.

MAY.

<i>Atmosphere.</i>	<i>T° Fahrenheit.</i>	<i>T° Fahrenheit.</i>	
	Degrees.		
Monthly mean	57.1	Mean daily range..... 9.3	
Maximum.....	85.0	Greatest daily range (19th) 15.5	
Minimum	31.0	Least daily range (23rd).. 1.5	
Mean daily range.....	22.5	<i>At Depth of Six Inches.</i>	
Greatest daily range.....	32.0	Monthly mean..... 56.3	
Least daily range.....	8.0	Maximum (31st)..... 66.0	
		Minimum (6th and 7th) . 43.0	
<i>Surface.</i>		Mean maximum. 56.7	
Monthly mean	56.7	Mean minimum..... 53.2	
Maximum (10th of month) 77.0		Monthly range	23.0
Minimum (5th).....	36.0	Mean daily range.....	4.65
Mean maximum.....	65.2	Greatest daily range (8th	
Mean minimum	49.9	and 19th.....	8.5
Monthly range.....	41.0	Least daily range (5th)...	1.0
Mean daily range	14.9	<i>At Depth of Twelve Inches.</i>	
Greatest daily range (19th) 25.0		Monthly mean	55.6
Least daily range (21st)...	4.0	Maximum (31st).....	64.0
<i>At Depth of One Inch.</i>		Minimum (6th and 7th) ..	46.0
Monthly mean	56.8	Mean maximum.....	56.6
Maximum (10th).....	74.5	Mean minimum.....	54.4
Minimum (5th).....	36.5	Monthly range.....	18.0
Mean maximum.....	62.9	Mean daily range.....	2.18
Mean minimum.....	49.5	Greatest daily range (8th).	4.5
Monthly range.....	38.0	Least daily range (3rd and	
Mean daily range.....	11.9	20th)	0.0
Greatest daily range (10th		<i>At Depth of Twenty-four Inches.</i>	
and 19th.....	20.0	Monthly mean	53.1
Least daily range (23rd) ..	1.0	Maximum (31st).....	58.0
<i>At Depth of Three Inches.</i>		Minimum (6th and 8th)...	48.0
Monthly mean	56.7	Mean maximum.....	53.4
Maximum (31st)	71.0	Mean minimum	52.8
Minimum (6th).....	40.0	Monthly range	10.0
Mean maximum.....	60.9	Mean daily range.....	0.48
Mean minimum	49.7	Greatest daily range (23rd)	2.0
Monthly range.....	31.0	Least daily range (on 12	
		days).....	0.0

124. Method of Whitney and Marvin.⁸⁴—The soil thermometer modified by Whitney and Marvin is shown in Fig. 13. The principle on which this modification depends is as follows:

⁸⁴ Agricultural Science, 8 : 28.

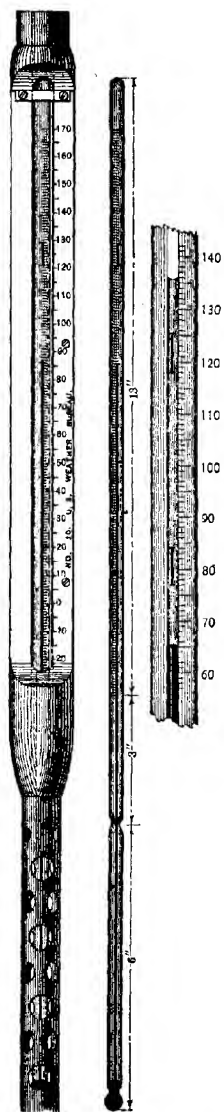


FIG. 13. SOIL THERMOMETER.

A mercurial thermometer of the ordinary construction is liable to give wrong indications of the temperature because it is difficult to determine the temperature of the column of mercury from the bulb to the surface of the ground. To avoid this source of error the thermometer figured was constructed.

The bulb of the thermometer is made quite small and a slender portion of the stem extends into its spherical portion in order to pass through the alcohol in the upper part of the bulb and extend into the mercury. The top portion of the thermometer stem does not differ in any essential respect from the stem of an ordinary thermometer.

The bulb is almost wholly filled with alcohol, which acts as the principal thermometric fluid and has the advantages of a high coefficient of expansion. The rest of the bulb and the stem of the thermometer up to a point convenient for graduation, are filled with mercury. The peculiar construction at this point is for the purpose of retaining the mercury about the point of the slender capillary stem inside the bulb and preventing the entrance of alcohol into that part of the stem when the thermometer is placed in a horizontal position.

In order to register the maximum and minimum temperatures a short column of alcohol is placed in the upper portion of the stem, above the mercury, and within this are arranged two small steel indexes, so constructed that they will not slide in the tube of their own weight, but are easily pushed upward by the mercury column or pulled downward by the top meniscus of the alcohol column. The indexes are set by means of a small magnet, the one being drawn down upon the top of the mercurial column and the other raised up against the meniscus of the alcohol column.

The rise of the mercury carries its index upward, leaving it to register the highest point reached, while the alcohol meniscus withdraws the other index and leaves it at a point representing the minimum temperature. It remains only to mention that the graduations are fixed in the usual way, having reference only to the positions of the mercurial column. Beyond the highest point supposed to be reached by the mercury, say about 120°, the graduations are extended in an arbitrary manner. The scale numbers represent temperatures by the mercurial column and are

continued in regular sequence beyond the 120° . On this plan the readings for minimum temperatures are on a purely arbitrary scale and are converted into true degrees of temperature by use of a table prepared for each thermometer, which table embodies as well all the corrections for instrumental error.

The arrangement of the alcohol column above the mercurial column and the indexes are shown enlarged at one side of the illustration. The readings of the maximum temperature are made from the bottom end of the index next to the mercurial column. The minimum temperature is the reading of the top of the uppermost index. Thus in the figure the maximum temperature indicated is 76.5° , and the minimum 125.7° , which, by reference to the table of correction for this thermometer, No. 10, is found to be 53.3° .

The use of mercury in the stem of the thermometer not only admits of the use of the index for registering the maximum temperature, but possesses the additional advantage of reducing the error due to uncertain temperature of the stem to about one-sixth what it would be if alcohol were used. Moreover, if necessary, as in the case with thermometers for greater depths than that figured, the ungraduated portion of the stem can be made of very much finer bore than the graduated portion, the effect of which is to diminish the objectionable error to a comparatively unimportant quantity.

The chief objection to thermometers of this construction is the liability of alcohol getting into the stem during the processes of construction, graduation and subsequent handling, and the difficulty of safely shipping them.

When once set up, however, there seems to be little or no possibility of derangement and the error common to mercurial thermometers due to rise of the freezing point with age does not apply owing to the high coefficient of expansion of the alcohol used in the bulb.

125. General Statement.—The form of thermometer employed is not of so much importance as the accuracy with which it is graduated and its intelligent use. Soil temperatures are of great importance in plant growth from the time of germination

of the seed until maturity is reached. They have most intimate relations also to bacterial growth upon which the fertility of the soil so greatly depends. The study of soil temperatures therefore is required in a systematic knowledge of the conditions of plant growth as influenced by the varying degrees of heat in the soil.

126. Applications of Soil Thermometry.—The estimation of the rapidity of absorption of heat by soils is conveniently made by means of a cubical zinc box, six centimeters square, which is filled with the sifted air-dried soil. The box, one side of which is left open, is encased snugly in a wooden cover, exposing only the open end, and placed for a few hours in the direct rays of the sun. The temperature is then observed at a given depth. The box may be provided with thermometers at different depths, the bulbs thereof extending to the center. In this case the box should be covered with thick felt instead of wood. The temperature of the layers of soils of different depths can thus be read off directly. The air temperature directly above the box should be accurately noted while the experiment continues.

Any other kind of box well protected against all heat save the direct sunlight on the open surface of the soil will answer as well as the one described.

To determine the action of moist earth in similar conditions the soil may be used in a wet state; the per cent. of moisture being determined in a separate portion of the soil or the amount of water added to the air-dried soil being noted.

127. Estimation of the Rapidity of Conductivity of Soils for Heat.—The bulb of a thermometer is placed in the middle of a mass of fine earth which is then exposed, best in a metallic box painted with lamp black, in a warm place. The time required for the thermometer to reach a certain degree is noted. By reversing the experiment and placing the mass of earth heated to a given degree in a cool place the speed of radiation can be determined by the time required for the mercury in the thermometer to fall to any given point.

The experiment may also be made by packing the soil by gently jolting it in a glass tube from six to eight centimeters in diameter. One end of the tube is closed with a piece of metal or fine

wire gauze painted with lamp black and is exposed to the source of heat. The bulb of a thermometer is placed at a given distance from the end of the tube and the time required for the mercury to be affected observed.

COHESION AND ADHESION OF SOILS

128. Behavior of Soil After Wetting.—The deportment of a soil when thoroughly wet in respect of its physical state on drying out is a matter of great practical concern to the agronomist. Some soils on becoming dry fall into a pulverulent state and are easily brought into proper tilth; others become hard and tenacious, breaking into clods and resisting ordinary methods of pulverization. The physical laws which determine these conditions depend largely on the principles of flocculation soon to be described. The present task is to describe briefly some of the methods of estimating the force of cohesion and adhesion.

129. General Method.—The fine air-dried earth is mixed with enough water to make a paste and molded into forms suitable for trial in a machine for testing strength of cement, etc. The forms most used are cakes from three to five centimeters in length and from one to two centimeters thick. These are used for determining crushing power. For the determination of longitudinal adhesion the paste may be molded in prismatic or cylindrical shape.⁸⁶ The prisms should show from one to two centimeters in cross section or the cylinder be from one to two centimeters in diameter. Before use they are to be exposed for several days until thoroughly air-dried. The force required to separate or crush these prepared pieces will measure the adhesive or cohesive property of the sample. A great number of trials should be made and the mean calculated.

130. Methods of Conducting Tests in Bureau of Chemistry.—The general and particular methods of conducting tests of cohesion and adhesion of molded fine rock material and earth have been worked out in detail in the road material laboratory (division of tests) of the Bureau of Chemistry.⁸⁶

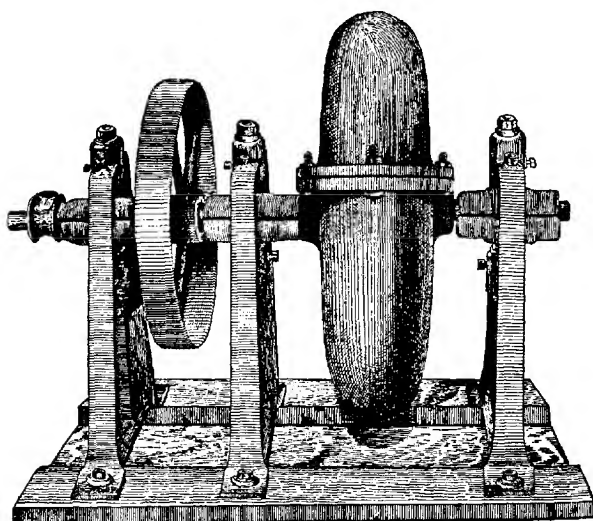
⁸⁵ Haberlandt, *Forschungen auf dem Gebiete der Agricultur-Physik*, 1 : 148.

⁸⁶ Bulletin No. 79, Bureau of Chemistry, 25.

The cementing value of a prepared cylinder of fine earth is a useful measure of its adhesive qualities. This is determined in this Bureau as follows:

CEMENTATION TEST.^a

The binding or cementing power of rock dust is such an important element in road building that much time has been spent in the endeavor to devise a suitable test for determining the degree to



which the various rocks and gravels possess this property. Many tests have been tried, but as yet only an impact test, carried on in a uniform manner as described below, has given satisfactory results.

^a This test, and the necessary machines for conducting it, were designed and developed by Page for the Massachusetts Highway Commission and the Road Material Laboratory. The impact machine at present used was built especially for this laboratory by the Maryland Geological Survey, under the direction of Mr. A. N. Johnson, highway engineer to the survey, who made several useful modifications in the machines.

One kilogram of the rock to be tested is broken sufficiently small to pass a 6 mm., but not a 1 mm. mesh screen. It is then placed in a ball mill and is ground for two hours and a half. This ball mill, shown in Fig. 14, contains two chilled iron balls which weigh 25 pounds each, and is revolved at the rate of 2,000 revolutions per hour. It was found by experiment that grinding rock thus prepared for two hours and a half was sufficient to reduce it to a powder that would pass through a 0.25 mm. mesh. The rock dust or fine earth is mixed with water to the consistency of a stiff dough and is kept in a closed jar for twenty-four hours. About 25 grams of this dough are placed in a cylindrical metal die, 25 mm. in diameter, which can be seen in Fig. 15. A closely fitting

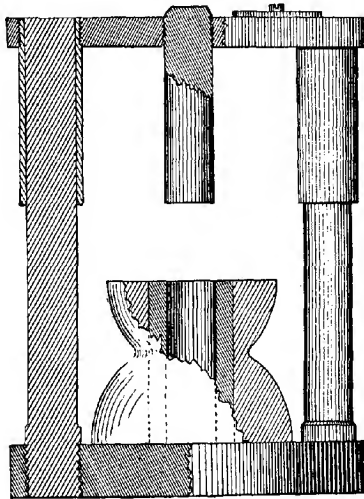


Fig. 15.

plug, supported by guide rods, is inserted over the material, which is then subjected to a pressure of 100 kg. per square centimeter.

It is most important that these briquettes should be compressed in a uniform manner, and for this a special machine has been designed (Fig. 16). The die is placed on an iron platform supported by a piston rod, which is connected directly with a hydraulic pis-

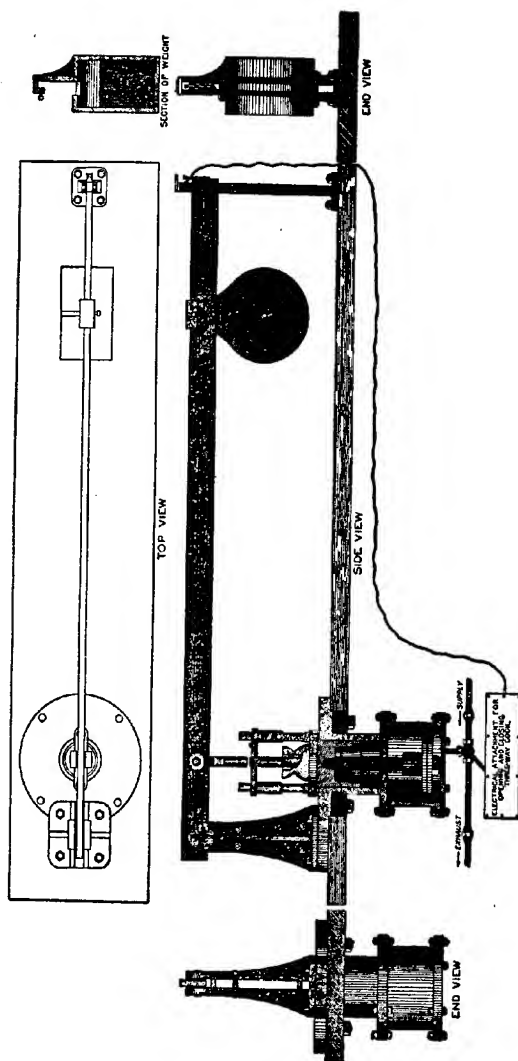
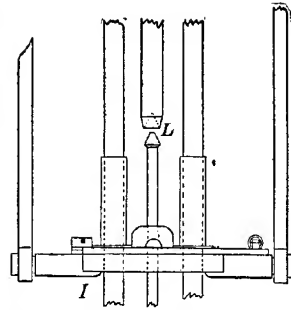
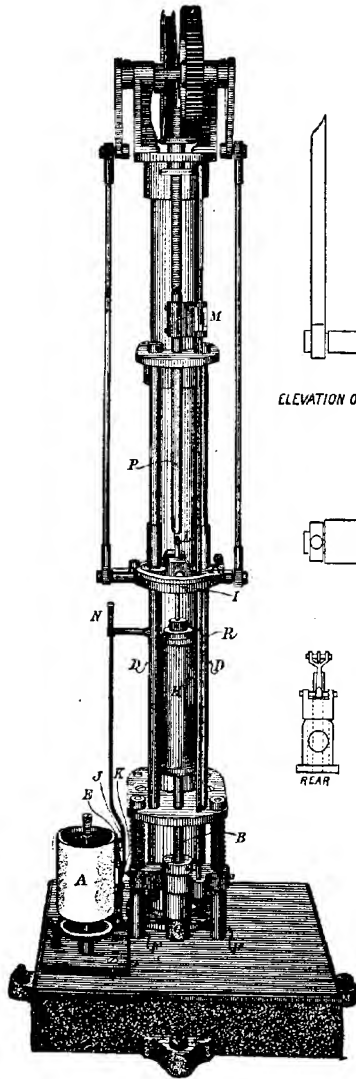


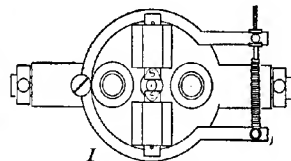
Fig. 16. Briquette Machine.

ton below. Water from a tank is admitted to the hydraulic cylinder through a small orifice in the pipe. As the piston rises the platform and die are carried up with it, the plug of the latter coming in contact with a yoke attached to a properly weighted lever arm. When the lever arm is raised one-eighth of an inch it closes an electric circuit which trips a right-angle cock, shutting off the water and opening the exhaust. One minute is required to compress a briquette, and the maximum load is applied only for an instant. By this device practically uniform conditions are obtained.

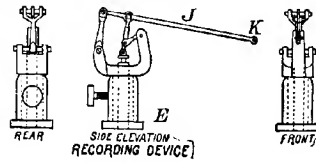
The height of the briquette is measured, and if it is not exactly 25 mm. the requisite amount of material is added or subtracted to make the next briquette the required height. Five briquettes are made from each test sample, and allowed to dry twelve hours in air and twelve hours in a steam bath. After cooling in a desiccator they are tested by impact in a machine especially designed for the purpose (Fig. 17). It consists of a 1 kg. (2.2 pounds) hammer (*H*), which is guided by two vertical rods (*D*). The hammer (*H*), which ends in a small cone at the top (*L*), is caught on the lower side of the cone by two spring bolts, and is lifted by a crosshead (*I*) which is joined to a crank shaft above. A vertical rod (*P*), which is directly over the hammer cone, can be adjusted by thumbscrews to give a drop to the hammer varying from a fraction of a millimeter to 10 cm. This rod has a hollow cone at its lower end into which the cone of the hammer head is thrust when the hammer is lifted by the crosshead (*I*). When the cone of the hammer head is brought into the cone of the adjusting rod the hammer is exactly centered and brought free of the guide rods (*D*). As the crosshead (*I*) continues to rise, the bolts supporting the hammer, which are tapered at an angle of about 45°, are thrust open by the sloping head of the adjusting cone rod (*P*) releasing the hammer, which falls on a flat-end plunger (*B*) of 1 kg. weight, which is pressed upon the briquette (*O*) by two light spiral springs surrounding the guide rods (*F*). This plunger (*B*) is bolted to a crosshead (*G*). A small lever (*J*) holding a brass pencil (*K*) at its free end, is connected with the side of the crosshead, by a link motion arranged so that it gives a vertical movement to the pencil five times as great as the movement of the



ELEVATION OF HAMMER LIFT AND DEVICE FOR TRIPPING HAM



PLAN OF HAMMER LIFT.



crosshead. The pencil is pressed against a drum (*A*), and its movement is recorded on a slip of silicated paper fastened thereon. The drum is moved automatically through a small angle at each stroke of the hammer; in this way a record is obtained of the movement of the crosshead during and after each blow of the hammer. To the crosshead (*G*) is fastened a steel rod (*R*) which passes up through the crosshead (*I*) and through a piece of metal securely attached to the cone rod (*P*). At this junction a vernier scale is graduated, by means of which the height of blow of the hammer can be accurately set to 0.1 mm., and by lowering the cone rod until it rests on the hammer cone (*L*) the height of the briquette can also be measured to 0.1 mm.

The standard fall of the hammer for a test is 1 cm. (0.39 inch) and this blow is repeated until the bond of cementation of the material is destroyed. The blow producing failure is easily ascertained, for when the hammer falls on the plunger, if the material beneath it can withstand the blow it recovers; if not, the plunger stays at the point to which it is driven, and in either case the behavior of the test piece is recorded on the drum. The automatic record thus obtained from each briquette is filed for future reference. A copy of one of these records is shown in Fig. 18. The



Fig. 18.

number of blows required to destroy the bond of cementation or resilience, as described above, is noted and the average obtained upon five briquettes is given as the cementing value.

The problem of holding the test piece rigidly under the intervening plunger, so that it may not be subjected to lateral movements and transverse strains, is one which has given much difficulty. Until recently a small brass plate with a beveled hole slightly larger than the diameter of the briquette was used, but it was found that the test piece was often seriously abraded by the side thrust developed. Later attempts to secure the briquette by various clamping devices were not satisfactory. Finally the meth-

od was adopted of placing a drop of thick shellac on the bottom of the test piece, which caused it to adhere firmly to the bedplate. Careful attention to such details as these is necessary in order to get satisfactory results from this test.

131. Method of Heinrich.—This process consists in mixing the air-dried earth with water until its aqueous content is 50 per cent of the highest water capacity determined by experiment.⁶⁷ The sample is next placed between two pieces of sheet iron 10 centimeters square, each of which in its middle point is provided with a hook. The thickness of the layer between the two pieces of iron should be from 5 to 10 centimeters. The exuding particles of soil are cut off with a knife. The upper piece of sheet iron is next suspended by a cord in such a way that the iron piece occupies a horizontal position. A small basket is attached to the lower surface and sand added thereto, little by little, until the column of earth is separated. The sand basket and iron plate are weighed, and the total weight gives the power necessary to separate a column of soil 10 centimeters square in cross section. The iron plates may be roughened so that the adhesion thereto of the soil is greater than its cohesive force.

132. Adhesion of Soil to Wood, Iron, Etc.—The adhesive power of moist soil for wood, iron, etc., is measured by Heinrich in the following way: The soil is mixed with water, as above, until it contains just 50 per cent. of its total water-holding content. It is then placed in a large vessel and the upper surface made as smooth as possible. A plate of wood, iron, etc., of 10 centimeters square is then pressed on the surface until a complete contact is secured. This plate, by means of a hook and cord passing over a pulley, is then subjected to stress by weighting the cord which carries a basket for that purpose. The basket should be of the same weight as the plate in contact with the soil. The weight added to the basket necessary to separate the plate from the soil is taken to represent the cohesive force. The author of the method appears to take no account of the pressure of the air on the plate caused by the exclusion of the air from its under surface.

133. Flocculation.—The union of very fine soil particles to form flocks is a phenomenon of great importance in the mechan-

⁶⁷ Grundlagen zur Beurteilung der Ackerkrume, 1882, 226.

ical analysis of soil in which the fine particles are separated in water. This subject will be discussed in part fifth in connection with silt separation.

THE ABSORPTIVE POWER OF SOILS FOR SALTS IN SOLUTION

134. **General Principles.**—It is a fact of every-day observation that soils have a particular property of absorbing certain materials with which they come in contact.⁶⁸ If it were not for this property all our wells would soon become unwholesome from the reception of decayed animal and vegetable matter carried to them in the drainage water from the surface. It is also a well-known fact that burying dead bodies prevents the gaseous products of decomposition from reaching and vitiating the atmosphere.

Besides this well-known power of soils to absorb the decomposition products of animal and vegetable matter, they also possess a property which is of far greater importance in plant economy; that is, the power of withdrawing and retaining certain mineral constituents from their solutions. Some theoretical data in relation to this phenomenon will be given in another place.

As far back as the sixteenth century mention is made by Lord Bacon of a process for obtaining pure water on the seashore by simply digging a hole in the sand and allowing it to fill with filtered sea water, which by this means, he alleges, is deprived of its salts. Bacon probably overestimated the power of sand for removing salt from solution but he recognized a property in soils which is of the greatest importance. His general conclusion is, "that ordinary soils possess the power of separating from solution and of retaining for the purposes of vegetation the bases of the different alkaline salts and certain animal and vegetable substances and that this power extends to all those substances to which we attach the chief value as manure." Although certain facts were observed by some of the earlier writers in regard to soil absorption, no systematic researches were conducted with a view of demonstrating the extent and cause of this power until within a comparatively few years.

¹ In 1850 Prof. I. Thomas Way published in the *Journal of the*

⁶⁸ Huston and Goss, Purdue University Agricultural Experiment Station, Bulletin, 33, 2 : 46.

Royal Agricultural Society of England, the results of a thorough and most excellent investigation of the subject. The classical researches of Way have served as a basis for all subsequent investigations and in the main the conclusions he reached have been confirmed. Since then many distinguished chemists, such as Henneberg, Stohmann, Peters, Heiden, Knop, Ullik, Pillitz, Biedermann, Tuxen, Hilgard and others have given their attention to this matter.

135. Summary of Data.—If a solution of a soluble sulfate, chloride or nitrate of an alkali or an alkaline-earth metal be placed in contact with a soil, a part of the base is withdrawn but none of the acid. This absorption of base is attended with the liberation of some other base from the soil combining with the acid of the solution. Any alkali or alkaline earth base has the power of replacing any other such base. However, if soluble phosphates and silicates of these bases be placed in contact with the soil both the base and the acid are removed from the solution.

Peters has shown that the amount of absorption depends upon the concentration of the solution, the relation between the quantity of solution and the soil and the kind of salt used.⁸⁹ He treated 100 grams of earth with 250 cubic centimeters of solutions of different potash salts with the following results:

Strength of solution.	$\frac{1}{10}$ Normal.	$\frac{1}{20}$ Normal
Salt Used	Grams K ₂ O absorbed.	Grams K ₂ O absorbed.
KCl.....	0.3124	0.1990
K ₂ SO ₄	0.3362	0.2098
K ₂ CO ₃	0.5747	0.3154

Beidermann proves that, for phosphoric acid at least, the absorption increases with the temperature.⁹⁰

It has also been found that the amount of absorption depends upon the time of contact between the soil and solution. Way found that the absorption of ammonia was complete in half an hour, while Henneberg and Stohmann noticed that the phosphoric acid continued to be fixed after the expiration of 24 hours.⁹¹

⁸⁹ Knop, *Agricultural Chemistry*.

⁹⁰ Beiträge zur Frage der Bodenabsorption.

⁹¹ Journal für Landwirtschaft, 1859, New Series, [3], 25.

It is a very important fact that the absorption of a base is never complete; no matter how dilute the solution it will still carry a small portion of the base with it. Peters states that it requires about 28,000 parts of water to remove one part of absorbed potash and Stohmann found that it required about 10,000 parts of water to remove one part of absorbed ammonia. With phosphoric acid, the resulting compound seems to be much more insoluble.

According to Tuxen nitrate of soda and common salt diminish the capacity of the soil to absorb ammonia and potash and increase its capacity to absorb phosphoric acid.⁹² Both nitrate of soda and common salt dissolve the potash combined in the soil in larger quantities than water alone.

136. Cause of Absorption.—The withdrawing and fixing of phosphoric acid from solutions by the soil is not very difficult to understand as this acid forms insoluble compounds of iron, lime, and magnesium, some or all of which bases are present in all soils. As to the absorption of the alkalis, the explanation is far more difficult as nearly all of their ordinary compounds are readily soluble in water. It appears from researches conducted in the Bureau of Chemistry by Cushman that clay in a colloidal state has the property of dissociating to a certain extent potash salts and entangling the basic ion in the meshes of the colloid structure. For instance, if a solution of potassium chlorid is shaken with clay and poured upon a filter a part of the potash will be missing in the filtrate although all the chlorine passes through.

As lime is usually found combined with the acid part of an alkali salt, from which the base has been absorbed by the soil, it might naturally be supposed that the absorptive power of the soil would depend upon the amount of lime present. Way found, however, that the addition of chalk in no way influenced the absorption of ammonia by a soil which contained but a small amount of lime. This fact was also confirmed by Knop who found that chalk exerted no influence on the absorption of ammonia salts.⁹³ These facts would seem to point to the conclusion that lime was present in sufficient quantity in these experiments, or that it is not essential to the phenomena of absorption. However, as any

⁹² Die Landwirtschaftlichen Versuchs-Stationen, 1882, 27 : 113.

⁹³ Die Bonitirung der Ackererde, 1871, 49.

alkali or alkaline-earth base can under certain conditions replace any other such base, the presence of lime in the filtrate from a soil treated with water is probably more of an accidental occurrence, owing to the comparatively large amount of that substance in most soils, than a necessary condition, as any other base would doubtless answer the same purpose in the absence of lime.

137. **Warrington** has shown that hydrated oxides of iron and aluminum, and especially the former, are capable of absorbing potash and ammonia, and as more or less of these hydrates exist in nearly all soils, a part, at least, of absorptive phenomena is to be ascribed to them, and this fact seems in harmony with the colloid theory of absorption mentioned above.⁶⁴

138. **Way** tried to determine which of the constituents of a soil exercised chiefly the absorptive power.⁶⁵ He passed a solution of ammonia through tubes containing pure sand and found that it came through apparently unaltered from the first, while a soil treated in the same way removed the ammonia for a considerable time. He concluded from this that the absorptive power does not exist in the sand. He next oxidized the organic matter in a soil with nitric acid and then treated it with ammonia in the same way. The first portion of the filtrate showed no ammonia in any form, hence he concluded that organic matter is not essential to the act of absorption. Clay was shown to have a higher absorptive power before than after burning. This would indicate that the power of absorption is related in some way to the form of the colloid structure. Some kinds of burned clay as powdered clay tobacco pipes, however, are capable of causing absorption phenomena.

Having shown that clay was the main constituent in a soil which caused the absorption of alkalis, he tried next to trace the particular compounds which caused the absorption. Having tried various natural silicates he at last succeeded in producing a hydrated silicate of aluminum and soda which exhibited displacement and absorptive properties very similar to those shown by the soil.

As Way had succeeded in producing an artificial hydrated silicate possessing absorptive properties Eichorn thought of trying

⁶⁴ Journal of the Chemical Society, London, 1868, 21.

⁶⁵ Journal of the Royal Agricultural Society, 1850, 313-379.

natural hydrated silicates or zeolites and found that they exhibited the same power as Way's artificial preparation.⁹⁶ It has also been shown by Beidermann, Rautenberg,⁹⁷ and Heiden⁹⁸ that the absorptive power bears a close relation to the amount of soluble silicates present.

In view of these facts it is now generally accepted that the absorption of salts of the alkalis, accompanied by the change of base, is due chiefly to the presence of decomposed zeolite minerals in the soil.

Besides the purely chemical absorption of salts by the soil, we have a physical absorption of various substances similar to the action of charcoal when used as a filter.

139. Conclusions of Armsby.—The data connected with the absorption of bases by a soil have also been reviewed by Armsby.⁹⁹ He shows that the absorption is accompanied by a chemical reaction between the salt whose base is absorbed and some constituent of the soil, and this change seems to be due particularly to certain zeolite silicates, although Liebig and others are disposed to credit this absorption largely to physical causes.

Knop advances the idea that the soil has the power of disintegrating salts in the presence of some substances like calcium carbonate which can unite with the acid. In experiments made with hydrous silicates it was shown that the absorption resembled in all cases like phenomena in the soil; hence the supposition already advanced in regard to the influence of such silicates is doubtless true.

In respect of absorption in general, the following conclusions are reached:

1. The absorption of combined bases by the soil consists in an exchange of bases between the salt and the hydrous silicates of the soil.
2. This exchange, which is primarily chemical, is only partial, its extent varying;

⁹⁶ *Landwirtschaftliches Central-Blatt*, 1858, 2 : 169.

⁹⁷ *Journal für Landwirtschaft*, New Series, 1862, 7 : 49.

⁹⁸ *Annalen der Landwirtschaft in der Königlich Preussischen Staaten*, 43 : 310.

⁹⁹ *American Journal of Science*, [3] 1877, 14 : 75.

- (a) with the concentration of the solution ;
- (b) with the ratio between the volume of the solution and the quantity of soil used.

3. The cause of these variations is probably the action of mass or the tendency of resulting compounds to reform the original bodies, the absorption actually found in any case marking the point where the two forces are in equilibrium.

140. Selective Absorption of Potash.—As a rule more potash is absorbed from the sulfate than from the chlorid. This fact would seem to point to the advisability of using sulfate as a fertilizer in preference to chlorid. However, as with the exception of nitrates, the absorptive power of a soil for the salts used as fertilizers, is many times greater than it is ever called upon to exert in fixing applied fertilizers, we need not trouble ourselves in regard to the absorption of phosphoric acid, potash or ammonia, in so far as the practical side of the matter is concerned. For example, an acre of soil to the depth of nine inches weighs about 900 tons. Now it has been found by Huston, that 100 parts of a soil experimented upon absorbed over 0.25 part of P_2O_5 , hence 900 parts would absorb over 2.25 parts of P_2O_5 ; or an acre of this soil to the depth of nine inches would absorb over two and one-fourth tons of phosphoric acid.¹ For field crops 500 pounds of a high grade phosphoric fertilizer is often employed containing about 100 pounds of P_2O_5 ; hence the power of such a soil to absorb phosphoric acid is more than 45 times as great as it is called upon to exert in fixing the phosphoric acid added to it as a fertilizer in such a case.

Huston has further shown that an acre of soil nine inches deep will absorb more than 2.7 tons of potash (K_2O) from potassium chlorid, from which salt less potash is absorbed than from the sulfate. If one-tenth ton of potassium chlorid per acre is an average dressing of potash for field crops, this soil possesses the power of absorbing more than 27 times as much potash as is applied as a fertilizer.

In like manner it may be shown that the power of an acre of soil nine inches deep to absorb ammonia from ammonium sulfate is more than 32 times as great as it would be called upon to exert

¹ Manuscript communication to author.

in fixing the ammonia from a dressing of one-quarter ton of ammonium sulfate per acre.

With sodium nitrate, however, there is no absorption; hence great care is necessary in the application of nitrogen as a nitrate, for, if it be put on in large quantities, at a season when the plant is not prepared to assimilate it, or during a period of heavy rains, there must unavoidably result loss from drainage. The best time to apply a nitrate is evidently during the active growing season.

141. Relation of Absorptive Power to Fertility.—It has been shown by King that there is a direct relation between the fertility of a soil and its power to absorb certain salts.² Especially is this true of potash. The absorption of potash in four typical Northern soils is nearly double that of four typical Southern soils. In every case the soil removing the most potash from the solution used gave the largest yield.

142. Effect of Area.—The surface area of soil particles in respect of their power to absorb solutions of salts, is a factor of great importance. The finer the particles of a soil the greater the surface area it presents and consequently the greater surface attraction. The approximate surface area of a cubic foot of each of the different typical soils of Maryland as estimated by Whitney is as follows:³

Pine barrens	23,940 square feet.
Garden lands.....	74,130 " "
Tobacco lands.....	84,850 " "
Wheat lands.....	94,540 " "
River terrace	106,260 " "
Limestone subsoil	202,600 " "

It will be seen that there are about 24,000 square feet of surface area in a cubic foot of the subsoil of the pine barrens, no less than 100,000 square feet or two and three-tenths acres of surface area in a cubic foot of the subsoil of the river terrace, and 200,000 square feet of surface area in a cubic foot of the limestone subsoil.

² Investigation in soil management, privately published, Madison, Wis., 114.

³ Maryland Agricultural Experiment Station, Fourth Annual Report, 282.

Bulletin No. 4, Weather Bureau, 14.

These figures seem vast, but they are probably below rather than above the true values, on account of the wide range of the diameters of the clay group. This great extent of surface and of surface attraction, which has been described as potential, gives the soil great power to absorb moisture from the air, and to absorb and hold back mineral matters from solution. A smooth surface of glass will attract and hold, by this surface attraction, an appreciable amount of moisture from the surrounding air. A cubic foot of soil, having 100,000 square feet of surface, should be able to attract and hold a considerably larger amount of moisture.

It might have been added that if the potential of the surface, separating the solution from the soil, be greater than the potential in the interior of the liquid mass, there will be a tendency to concentrate the liquid on this surface of separation. It has been shown that certain fluids have greater density on a surface separating the fluid from a solid. On the other hand, if the potential were low there might be no tendency for this concentration, and even the reverse conditions would prevail and the soluble substance could be readily washed out of the soil.

143. Theory of Surface Tension.—The principles on which the phenomena of surface tension in soils are based have been clearly stated by Briggs.⁴ These phenomena are due to the action of certain molecular forces. In a drop of liquid the forces acting on a molecule at or near the center may be considered as producing equilibrium, while at or near the surface such is not the case.

144. Removal of Organic Matters.—It is probably largely due to this restraining power that organic matters are removed from solutions in percolating through the soil. Organic matter in the soil however is subjected to vigorous attacks by the bacteria with which it comes in contact, which not only destroy the protein matter but also both the soluble and insoluble carbohydrates.

145. Importance of Soil Absorption.—The importance of the absorptive power of the soil can hardly be overestimated. By means of this power those mineral ingredients of plant food, of which most soils contain but little, are held too closely to allow of

⁴ *The Mechanics of Soil Moisture*, Bull. 10, Division of Soils, U. S. Dept. of Agriculture, 7.

rapid loss by drainage, and still sufficiently available to answer the needs of vegetation, provided the store is large enough. The only important plant food in the soil which does not come under the influence of absorption is nitrogen in the form of salts of nitric acid, and nature has made a wise provision for this element by binding it in the form of insoluble organic bodies which nitrify but slowly, and by supplying each year a small quantity from the atmosphere.

By means of the absorptive power of soils the farmer, if he puts on an excess of potash or phosphoric acid as a fertilizer, does not lose it all but is able to reap some benefits from it in the next and even in succeeding crops. If it were not for this power of the soil in holding any excess of plant food which may be present or added, the best method for applying fertilizers would be a much more complicated problem than it is at present; and it would be necessary to apply them at just the proper season and in nicely regulated amounts to insure against loss.

The general principles which underlie the absorption, retention and release of plant foods in the soil belong to the domain of physical chemistry. The problem of equilibrium in the soil however is a most complicated one, due to the great number of active bodies and the ever varying conditions of temperature, moisture, bacterial activity and plant growth.

146. Method of Determining Absorption of Chemical Salts.—The soil which is to be used for this experiment should be treated as has been indicated and passed through a sieve the meshes of which do not exceed half a millimeter in size. From 25 to 50 grams of the fine earth may be used for each experiment.

The fine earth should be placed in a flask with from 100 to 200 cubic centimeters of the one-tenth to one-hundredth normal solution of the substance to be absorbed. The flask should be well shaken and allowed to stand with frequent shaking from 24 to 48 hours at ordinary temperatures. The mixture is then to be thrown upon a folded filter and an aliquot part of the filtrate employed for the estimation, corrected for the amount of water in the soil used. The methods of determining the quantities of the substances used will be found in other parts of this manual. It is recommended to conduct a blank experiment with water under

the same conditions in order to determine the amount of the material under consideration abstracted from the soil by the water alone. The difference in the strength of the solution as filtered from the soil, and the original solution will give the absorptive power of the soil for the particular substance under consideration.

If it should be desired to determine the absorptive power of the soil for all the ordinary chemical fertilizing materials at the same time, a larger quantity of the sample should be employed corresponding to the increased amount of the standard solutions used. About 500 cubic centimeters of the mixed salt solution should be shaken with 125 grams of the earth and the process carried on in general as indicated above. The absorption coefficient of an earth for any given salt according to Fesca, is the quantity of the absorbed material expressed in milligrams calculated to a unit of 100 grams of the soil.⁶

147. Method of Pillitz and Zalomanoff.—It is recommended by Pillitz and Zalomanoff to reject the old method, *viz.*, shaking the soil with the solution in a flask, and substitute the filtration method both because it gives a more natural process and because the results are more constant. The apparatus is shown in Fig. 19.

Two cylinders are placed vertically, one over the other. The lower cylinder is graduated in cubic centimeters, the upper cylinder is closed at each end by perforated rubber stoppers *a* and *b* through the openings of which the glass tubes *c* and *d* pass. Within the cylinder *a* the opening of the small tube *d* is closed with a disk of Swedish filter paper. The lower part of the small tube *d* is connected by means of a rubber tube carrying a pinch-cock *e* with another small tube *e* which passes through the stopper *f*. In carrying out the process the weighed quantity of soil is placed in the upper cylinder and afterwards the measured quantity of the solution, the whole thoroughly mixed and the cylinder closed. The valve *C* is then opened, a given quantity of the solution, but not all, is made to drop into the lower cylinder and the valve *C* is closed. The liquid which has passed into the lower cylinder as well as that which remains in the upper cylinder, is thoroughly

⁶ Beiträge zur agronomische Bodenuntersuchung, 31.

stirred and the quantity of the soluble material remaining in both liquids determined and the absorbing power of the soil estimated from their difference. It does not appear that this method of estimation of the absorption power possesses any special advantages over the old and far simpler method of shaking in a flask.

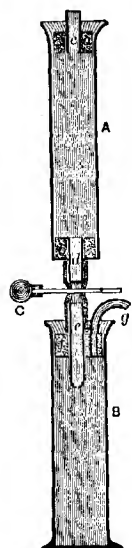


FIGURE 19.
PILLITZ'S
APPARATUS FOR
DETERMINING AB-
SORPTION OF
SALTS BY SOILS.

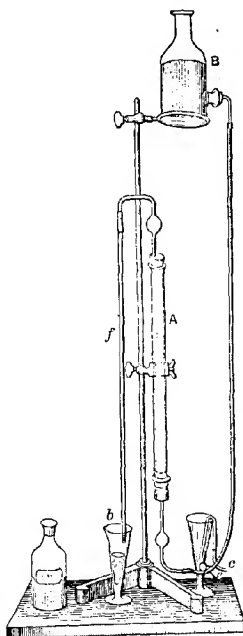


FIGURE 20.
MÜLLER'S APPARATUS TO SHOW AB-
SORPTION OF SALTS BY SOILS.

148. Method of Müller.—The method of Müller for illustrating absorption is carried out by means of the apparatus shown in Fig. 20. A glass cylinder A about 750 centimeters long and four to five centimeters wide is closed at each end with rubber stoppers with a single perforation.⁷ The cylinder A serves for the

⁷ Zeitschrift für angewandte Chemie, 1889, 13 : 501.

reception of the soil with which the experiment is to be made. Before using, the lower part of it is filled with glass pearls or broken glass and above this a layer of glass wool is placed about one centimeter thick. The object of this is to prevent the soil from passing into the small tube below. As soon as the soil has all been placed in the cylinder A the upper part of the tube is also filled with glass wool. The cylinder A is connected with the pressure bottle B by means of a rubber tube and the small glass bulb tube shown in the figure. The bottle B should have a content of about two liters. It is filled with the standard solution of the material of which the absorption coefficient is to be determined. At *c* the rubber tube is connected with a glass T, one arm of which is provided with a piece of rubber tubing which can be closed by means of a pinch-cock. At *e* a screw pinch-cock is placed which can be used to regulate the flow of the solution from B to A. By opening the pinch-cock at *c* on the short arm of the T piece, a sample of the original liquid can be removed and this can be compared with the part which runs to *b*. If it is desired for instance, to show that potassium carbonate has been absorbed by the soil the two bulbs shown on the small glass tubes connecting with A can be filled with red litmus paper. This paper will at once be turned blue in the lower bulb while in the upper one it will retain its original color because the liquid in passing through the soil will have lost its alkaline reaction. The solution used should be very dilute. The apparatus is designed particularly for lecture experiments rather than for quantitative determinations.

149. Method of Knop.—For rapid determination of the absorption coefficient of the soil Knop's method may be used.⁸

The fine earth which is employed is that which passes a sieve with meshes of half a millimeter. From 50 to 100 grams of this soil are mixed with from five to 10 grams of powdered chalk and with from 100 to 200 cubic centimeters of ammonium chloride solution of known strength. The ammonia solution should be of such a concentration that the ammonia by its decomposition for each cubic centimeter of the liquid evolves exactly one cubic cen-

⁸ Die Bonitierung der Ackererde, Leipzig, 1872, 49.

Wahnschaffe, Anleitung zur wissenschaftlichen Bodenuntersuchung, 133.

timeter of nitrogen. This solution is prepared by dissolving in 208 cubic centimeters of water at 17°.5 one gram of ammonium chlorid. With frequent shaking the solution is allowed to stand in contact with the soil for 48 hours. The whole is now allowed to settle and the supernatant clear liquid is poured through a dry filter. From the filtrate from 20 to 40 cubic centimeters are removed by a pipette, and evaporated to dryness in a small porcelain dish, with the addition of a drop of pure hydrochloric acid. The ammonium chlorid remaining in the porcelain dish is washed with 10 cubic centimeters of water into one of the compartments of the evolution flask of the Knop-Wagner azotometer. It is decomposed with 50 cc. of hypobromite of soda diluted with 200 cc. of water and the nitrogen estimated volumetrically. The hypobromite is prepared by dissolving 100 grams of sodium hydrate in 250 cc. of water and adding to the lye 25 cc. of bromin. The difference between the amount of nitrogen in this material and that of the original will give the amount of absorption exercised by the fine earth. Any of the standard methods of determining nitrogen described especially in the second volume of this work may be used instead of the method just given.

150. Method of Huston.—The salt solutions used in the experiments conducted by Huston are sodium phosphate (Na_2HPO_4), potassium chlorid, potassium sulfate, ammonium sulfate and sodium nitrate.⁹

The solutions should be approximately tenth normal, the actual strength in each case being determined by analysis. The phosphorus is determined as magnesium pyrophosphate in the usual way, the potash as potassium platinochlorid, the ammonia by collecting the distillate from soda in half normal hydrochloric acid and titrating with standard alkali, and the nitrate by Warington's modification of Schlösing's method for gas analysis. The details of these methods of determination will be given later. One hundred grams of the sifted, air-dried soil are placed in a rubber-stopped bottle and treated with 250 cc. of the solution to be tested. The digestion is continued for 48 hours in each case, the bottles being thoroughly shaken at the end of 24 hours. At the end of the treatment the solutions are filtered and

⁹ Experiment Station, Purdue University, Bulletin 33, 50.

the salts determined in aliquot portions. The details of this method are essentially those already described.

151. Statement of Results.—Duplicate analyses should be made and the tabulation of the data is illustrated in the following analyses by Huston:

Na_2HPO_4 cubic centimeters filtrate.	Weight of $\text{Mg}_2\text{P}_2\text{O}_7$ in 25 cubic centimeters of the solution.	Weight of $\text{Mg}_2\text{P}_2\text{O}_7$ in filtrate.	P_2O_5 absorbed by 100 grams soil.	Salt removed per cent.
(a) 25	0.1368 gram	0.0962 gram		
(b) 25		0.0963 "	0.2589 gram	29.6
	Mean	0.0963 "		
KCl cubic centimeters filtrate.	Weight of K_2PtCl_6 in 25 cubic centimeters of solution.	Weight of K_2PtCl_6	K_2O absorbed by 100 grams soil.	Salt removed per cent.
(a) 25	0.6154 gram	0.4505 gram		
(b) 25		0.4540 "	0.3161 gram	26.5
	Mean	0.4523 "		
K_2SO_4 cubic centimeters filtrate.	Weight of K_2PtCl_6 in 25 cubic centimeters of solution.	Weight of K_2PtCl_6	K_2O absorbed by 100 grams soil.	Salt removed per cent.
(a) 25	0.6113 gram	0.4426 gram		
(b) 25		0.4371 "	0.3324 gram	28.0
	Mean	0.4399 "		
$(\text{NH}_4)_2\text{SO}_4$ cubic centimeters filtrate.	Number of cubic centimeters one-half normal acid neutralized by 50 cubic centimeters of solution.	Cubic centimeters Half normal acid neutralized.	N absorbed by 100 grams soil.	Salt removed per cent.
(a) 50	10.00	7.25		
(b) 50		7.25	0.0964 gram	27.5
	Mean	7.25		
NaNO_3 cubic centimeters filtrate.	Number cubic centimeters N_2O_5 afforded by 10 cubic centimeters of solution at 0° and 1000 millimeters pressure.	Cubic centimeters N_2O_5 at 0° and 1000 millimeters.	N absorbed by 100 grams soil.	Salt absorbed per cent.
(a) 10	16.63	16.77		
(b) 10		16.70	none	00.00
	Mean	16.73		

Upon comparing the figures it will be found that the absorption, passing from the greatest to the least, is as follows: phosphoric

acid (P_2O_5), potassium sulfate, ammonium sulfate, potassium chlorid and sodium nitrate.

It will be seen that there was no absorption in the case of the nitrate, while with each of the other salts there was quite a marked absorption. It will also be noticed that the percentages of absorption are not very different, and especially is this true of the potassium and ammonium salts, the P_2O_5 being somewhat higher. Whether this fact is merely an accidental occurrence or is due to the law of combination by equivalents could hardly be predicted from the single soil experimented upon; but taking into consideration the possibility of difference in solubility of the resulting compounds in the saline solutions used, and of other varying conditions, the percentages are evidently not far enough apart to exclude the possibility of the bases uniting in equivalent proportions.

152. Preparation of Salts for Absorption.—The salts employed in the determinations of absorption are conveniently prepared in fractional normal strength.

In grams per liter the following quantities are recommended, *viz.*, 5.35 g NH_4Cl ; 10.11 g KNO_3 ; 16.40 g $Ca(NO_3)_2$; 24.60 g $MgSO_4 + 7H_2O$; 2.34 g $CaH_4(PO_4)_2$.

The ammonium chlorid, potassium nitrate and magnesium sulfate can be weighed as chemically pure salts and the standard solution be directly made up. Calcium nitrate is so hygroscopic that a stronger solution must be made up, the calcium determined and the proper volume diluted to one liter.

Monocalcium phosphate is prepared as follows:

A solution of sodium phosphate is treated with glacial acetic acid and precipitated with a solution of calcium chlorid. It is then washed with water until all chlorin is removed. The fresh precipitate is saturated with pure, cold phosphoric acid of known strength. After filtering the solution is placed in a warm room and left for two or three weeks until crystallization takes place.

The crystals are pressed between blotting papers and finally dried over sulfuric acid and washed with water-free ether, and again dried. Since this salt is decomposed in strong solutions it should be used only in one hundredth normal strength, *viz.*, 2.34 grams per liter.

POROSITY AND ITS RELATIONS TO MOISTURE

153. Porosity.—The porosity of a soil depends upon the state of divisibility and arrangement of its particles, and upon the amount of interstitial space within the soil. If a soil be cemented together into a homogeneous mass, its porosity sinks to a minimum; if it be composed, however, of numerous fine particles, each preserving its own physical condition, the porosity of the soil will rise to a maximum. The porosity of a soil may be judged very closely by the percentage of fine particles it yields by the process of silt analysis to be described further on. In general, the more finely divided the particles of a soil, the greater its fertility. This arises from various causes; in the first place, such a soil has a high capacity for absorbing moisture and holding it; thus the dangers of excessive rain-falls are diminished, and the evil effects of prolonged drought mitigated. In the second place, a porous soil permits a freer circulation of the gases found in the soil. The influence of lime in securing the proper degree of porosity of a soil is very great, especially in alluvial deposits and other stiff soils. It prevents the impaction which will necessarily follow in a soil which is too finely divided. In general, the porosity of the soil may be said to depend on three factors, *viz.*: 1. Upon the state of divisibility or the number of particles per unit volume; 2. Upon the nature and arrangement of these particles; 3. Upon how much interstitial space there is in the soil.

154. Influence of Drainage.—Good underdrainage increases the porosity of a soil by removing the excess of water during wet seasons and rendering the soil more sensitive to capillary attraction which will supply moisture during dry seasons. The influence of tile drainage on the production of floods has been carefully studied by Kedzie, who shows that surface ditching in conjunction with deforesting may increase floods and contribute to droughts, and that tile-drainage may increase flood at the break-up in spring, when the water accumulated in the surface soil by the joint action of frost and soil capillarity during the winter, and the surface accumulations in the form of snow are suddenly set free by a rapid thaw.¹⁰

¹⁰ Proceedings of the Ninth Meeting of the Society for the promotion of Agricultural Science, 1888, 46.

He also points out that during the warm months tile-draining tends to prevent flood by enabling the soil to take up the excessive rain-fall and hold it in capillary form, keeping back the sudden flow that would pass over the surface of the soil if not absorbed by it, and it mitigates summer drought by increased capacity of the soil to hold water in capillary form and to draw upon the sub-soil water supply.

155. Soil Moisture.—The capacity of a soil to absorb moisture and retain it depends on its porosity and is an important characteristic in relation to its agricultural value.

The following general principles relating to soil moisture are adapted from Stockbridge.¹¹

During dry weather plants require a soil which is absorptive and retentive of atmospheric moisture. The amount of this retention is generally in direct ratio to two factors, *viz.*, the amount of organic matter and its state of division. The capillary water of the soil is very closely related to its percolating power, since all waters in the soil are governed in their movements by what is known as capillary force. Liebenberg has shown that this movement may be either upwards or downwards, according as the atmosphere is dry or supplies soil-saturating rain. The water absorbed by the roots passes into the plant circulation, and the greater part is evaporated from the leaves. Where the supply of water is insufficient, the plant wilts, and if the evaporation long continue in excess of the supply obtained from the soil, the plant must die. The experiments of Hellriegel have shown that any soil can supply plants with all the water they need, and as fast as they need it, so long as the moisture within the soil is not reduced below one-third of the whole amount that it can hold. The quantity of water required and evaporated by different agricultural plants during the period of growth has been found to be as follows:

One acre of wheat	exhales	409,832 pounds of water.
" " " clover	"	1,096,234 " " "
" " " sunflowers	"	12,585,994 " " "
" " " cabbage	"	5,049,194 " " "
" " " grape-vines	"	739,733 " " "
" " " hops	"	4,445,021 " " "

¹¹ Rocks and Soils, 155.

Dietrich estimates the amount of water exhaled by the foliage of plants to be from 250 to 400 times the weight of dry organic matter formed during the same time. Cultivation conserves soil moisture. It must be remembered that this water contains soil ingredients in solution. Hoffmann has estimated that the quantity of matter dissolved from the soil by water varies from 0.242 to 0.0205 per cent. of the dried earth. The experiments of Humphrey and Abbott have shown that a large part of the total sediment of the Mississippi river is soluble in water.

156. States of Water in Soil.—The water in the soil may be regarded as capable of movement and fixed. Any amount of water in the soil which is above that required for saturation is subject to the law of gravitation and tends to disappear by drainage. The quantity of water necessary to saturate a soil is that which is held in place by the attractions which are equal in magnitude to the attraction of gravity.

Whenever there is less water than the above amount capillary movement tends to distribute the rest so as to restore equilibrium, that is capillary movement is towards the driest part. Water which is not affected either by gravitation or capillary movement is fixed in its position by surface tension.

157. Surface Tension.—The force with which a liquid film attaches itself to a solid surface is a modification of molecular force known as surface tension. The nature and purity of the surface modify the surface tension. The presence of dissolved matters in the liquid also greatly modify the degree of attraction. Mercury in general exhibits the highest surface tension of bodies liquid at ordinary temperatures and water is next in order.

The water in soils is never pure but is always contaminated with a greater or less amount of organic and mineral matter in solution. Aqueous solutions of salts usually show a higher surface tension than water. Potash is a substance quite invariably found in soil waters. The following table given by Briggs shows the variations produced in surface tension by the kinds of potash salts and under the conditions of concentration specified.¹² The dyne measures the attraction between two gram masses at a distance of

¹² Mechanics of Soil Moisture Bulletin No. 10, Division of Soils.

1 cm. apart (from center to center) or in other words $1/_{980}$ of the force of gravitation on one gram mass.

SURFACE TENSION OF SOLUTIONS OF SALTS IN WATER.

Salt in solution	Density.	Concentration, ^a	Temperature, °C.	Surface tension, Dynes per cm.
KCl	1.170	25	15-16	82.8
KCl	1.101	15	15-16	80.1
KCl	1.046	7	15-16	78.2
NaCl	1.193	25	20	85.8
NaCl	1.107	15	20	80.5
NaCl	1.036	5	20	77.6
K ₂ CO ₃	1.357	35	15-16	90.9
K ₂ CO ₃	1.157	16	15-16	81.8
K ₂ CO ₃	1.040	5	15-16	77.5
KNO ₃	1.126	19	14	78.9
KNO ₃	1.047	7	14	77.6
MgSO ₄	1.274	24	15-16	83.2
MgSO ₄	1.068	6	15-16	77.8

^a. Approximate weight of the dissolved substance in 100 parts by weight of the solution

Briggs adds the observation that most organic substances found in soils, especially those of an oily nature, being insoluble in water and hence most evident on the surface, lower the surface tension to a marked degree. The tension of soil extracts, therefore, is generally much lower than that of pure water, in spite of the presence of dissolved salts.

158. Determination of the Porosity of the Soil.—The porosity of the soil is fixed by the relative volume of the solid particles as compared with the interstitial space. It is most easily determined by dividing the apparent by the real specific gravity.

Let the real specific gravity of a soil be 2.5445 and the apparent specific gravity of the same soil be 1.0990.

The porosity is then calculated according to the following ratios, *viz.*:

$$2.5445:1.099 = 100:x$$

Whence $x = 43.2 =$ per cent. volume occupied by the solid particles of the soil.

The per cent. volume occupied by the interstitial space is therefore 56.8.

159. Volume of Interstitial Space.—The total volume of interstitial space within the soil, in which water and air can enter, is determined by calculation from the specific gravity and the weight of a known volume of soil.¹³ For this purpose the soil is sampled

¹³ Whitney, Weather Bureau Bulletin 4, 23.

in the following way: A brass tube, about two inches in diameter and nine inches long, has a clock spring securely soldered into one end, and this end turned off in a lathe to give a good cutting edge of steel. The area enclosed by this steel edge is accurately determined, and a mark is placed on the side of the tube exactly 15 centimeters from the cutting edge. A steel cap fits on top of the brass cylinder to receive the blows of a heavy hammer or wooden mallet. The cylinder is driven into the ground until the six-inch mark is just level with the surface. The whole is then dug out, slipping a broad piece of steel under the cylinder before it is removed, so as to prevent the soil which it contains from falling out. The cylinder is then carefully laid over on its side, and the soil is cut off flush with the cutting edge of steel. The soil is removed from the cylinder, carried to the laboratory and properly dried and weighed. The object of the steel inserted in one end of the cylinder is to reduce the friction on the inside of the tube to a minimum, and thus prevent the soil inside the cylinder being forced down below the level of the surrounding earth. The volume of the soil removed with this sampler can readily be determined by calculation, as the area of the end of the tube is known and the sample is 15 centimeters deep. In a sampler, such as described here, this volume is about 300 cubic centimeters. From the weight of soil and the volume of the sample, the volume of interstitial space may be found by the following formula:

$$S = \frac{\left(V - \frac{W}{\omega}\right) \times 100}{V}$$

S is the per cent. by volume of interstitial space, V is the volume of the tube in cubic centimeters, W is the weight of soil in grams, and ω is the specific gravity of the soil. The specific gravity can be determined for each soil, or the factor 2.65 can be used, which is sufficiently accurate for most work.

The per cent. by volume of interstitial space in the undisturbed subsoil is found to range from about 35 for sandy land, to 65 or 70 for stiff clay lands.

For the determination of the amount of water an air-

dried soil will hold, if all the space within it is completely filled with water, an eight-inch straight Argand lamp chimney, with a diameter of about two inches, can be conveniently used. A mark is placed on the side of the tube, six inches from one end, and the volume of the tube up to this mark is found by covering the end with a piece of thin rubber cloth, or by pressing the chimney down firmly on a glass plate, and making a water-tight joint with paraffin or wax. Water is then poured into the tube up to the six-inch mark, and the weight or volume of water determined. The tube can then be dried, a piece of muslin tied tightly over the top and the whole then weighed. Soil is carefully poured in and the tube gently tapped on a soft support until the soil is six inches deep in the tube, and has the desired degree of compactness. The weight and volume of the soil can thus be determined, and the volume of the interstitial space got from the formula already given. This can also be determined directly by introducing water from above, or by immersing the cylinder of soil up to the six-inch mark in water, and allowing the water to enter the soil from below. With such a short depth of soil, very little water will flow out when the cylinder is suspended in the air. The amount which will flow out when the cylinder is thus suspended, will depend both upon the texture and the depth of soil. It is impossible, however, by this method, to completely remove the air or to completely fill the space within the soil with water; for as the water enters the soil, a considerable amount of air becomes entangled in the capillary spaces, and this could not be removed except by boiling and vigorous stirring, which would altogether change the texture of the soil. The amount of water held by the soil, or the amount of space within the soil into which water and air can enter, will evidently depend upon the compactness of the soil, and this is best expressed in per cent. by volume of space.

160. Porosity of Soil to Air.—King has proposed to gauge the porosity of the soil and thus its relations to the passage of water by its porosity to air.¹⁴

To this end the rate at which air at a given temperature and

¹⁴ Fifteenth Annual Report Experiment Station of Wisconsin, 1897, 123. Bull. 24, Bureau of Soils, 28.

under a given pressure passes through a column of given length of air-dried soil is determined. The apparatus employed is shown

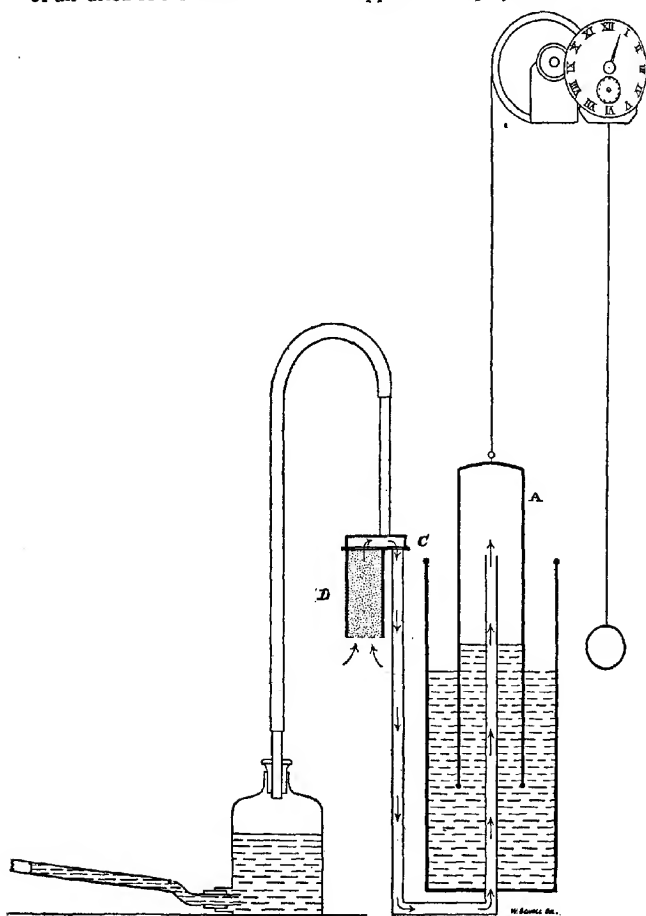


FIGURE 21. KING'S ASPIRATOR FOR DETERMINING THE "EFFECTIVE DIAMETER" OF SOIL PARTICLES,

in Fig. 21. The air-dried previously pestled soil is contained in the

tube D which has a capacity of from 100 to 200 cc. The aspirator A is an elongated gas meter attached to a pulley by a cord as indicated in the drawing. An air meter with index is geared to the aspirator. A water gauge capable of being read to 1 mm. is attached to the air chamber of the apparatus.

In filling the soil tube a light cap is attached to the lower end which is closed also with a fine rubber gauze. The finely divided soil sample is introduced in small quantities and gently tamped with a flat pestle until full. The tube is then firmly held against a solid body and struck repeatedly with a light hammer until no further settling takes place, meanwhile being kept quite full. The detachable solid bottom of the tube is then removed and the aspiration performed. The quantity of air passing is expressed in terms of "effective diameter" that is the diameter of a soil composed of spherical particles of the same size and lying as closely together as possible without compression, and which would have the same degree of permeability to air as the sample subjected to experiment. This diameter is computed by a formula constructed by Schlichter, which is as follows:¹⁵

$$d_e = .878 \frac{hk}{\sqrt{pt}}$$

where

d = diameter of grain in cm.

h = length of soil column in cm.

s = area of cross section of soil column in sq. cm.

p = pressure in cm. of water at 20° C.

t = time in sec. for 5,000 cc. of air to flow through at a temperature of 20° C.

The value of k is determined from the following table, being dependent upon the pore space, which must be measured independently.

Per cent. of pore space.	Log. k .	Per cent. of pore space.	Log. k .
26	1,9258	37	1,4173
27	1,8695	38	1,3816
28	1,8195	39	1,3445
29	1,7701	40	1,3078
30	1,7199	41	1,2725
31	1,6732	42	1,2374
32	1,6277	43	1,2024
33	1,5847	44	1,1690
34	1,5409	45	1,1370
35	1,4999	46	1,1058
36	1,4592	47	1,0729

¹⁵ Nineteenth Annual Report U. S. Geological Survey, Part II., 1897-8, 301.

Water Supply and Irrigation Papers, No. 67 U. S. Geological Survey, 1902.

161. Capacity of the Soil for Water.—The soil, as it is taken from the field, may have quite a different water coefficient from the same soil after it has been passed through a fine sieve or been dried at air temperatures or at 100° or 110°. The method of determination which depends upon adding excess of water to a given weight of fine earth, and afterwards eliminating the excess by percolation or filtration, is apt to give misleading results. If, however, the results are obtained by working on the same weight of soil, and in the same conditions, they may have value in a comparative way. The comparison between soils must be made with equal weights, in like apparatus and with the same manipulation, to have any value. These determinations, however, cannot have the same practical value as those made in the samples in a natural condition as has just been described.

162. Method of Wolff Modified by Wahnschaffe.—A cylindrical zinc tube, 16 centimeters long and four centimeters internal diameter, is used, the cubical capacity of which is 200 cubic centimeters.¹⁶

The cylinder is graduated by placing the moist linen disk on the gauze and tying a piece of rubber cloth over the bottom. Water is poured in until the level is even with the gauze bottom. Add then exactly 200 cubic centimeters of water, mark its surface on the zinc, throw out the water, and file the zinc cylinder down to the mark.

The bottom of the tube is closed with a fine nickel-wire gauze. Below this a piece of zinc tubing of the size of the main tube, pierced laterally with a number of holes, is soldered.

Before using, the gauze bottom of the cylinder is covered with a moist, close fitting linen disk, and the whole apparatus weighed. It is then filled with the fine earth, little by little, jolting the cylinder on a soft substance after each addition of soil to secure an even filling. When filled even full the whole is weighed, the increase in weight giving the weight of soil.

A large number of cylinders can be filled at once and placed in a large crystallizing dish containing water and covered with a bell

¹⁶ *Anleitung zur wissenschaftlichen Bodenuntersuchung*, Second Edition, 162.

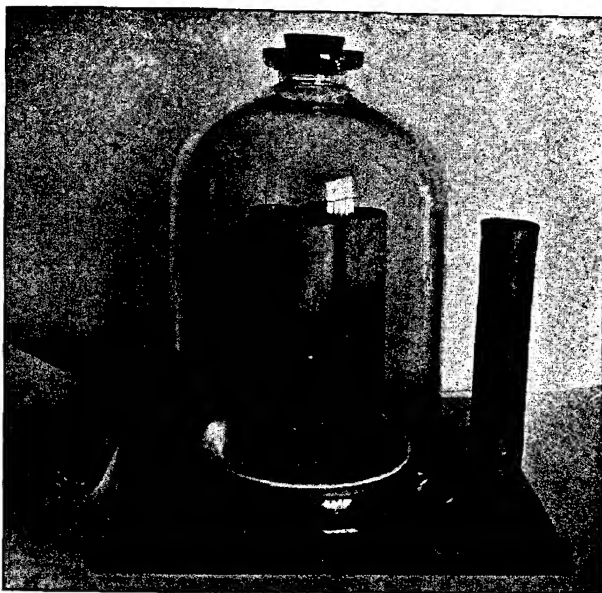


FIGURE 22.
CAPACITY OF THE FINE SOIL FOR HOLDING MOISTURE. APPARATUS USED IN
BUREAU OF CHEMISTRY.

jar. (Fig. 22). The water should cover the gauze bottoms of the cylinders to the depth of from 5 to 10 millimeters. More water should be added from time to time as absorption takes place. The cylinders should be left in the water until when weighed at intervals of an hour no appreciable increase in weight takes place. The temperature and barometer reading should be noted in connection with each determination. With increasing temperature the coefficient of absorption is diminished.

The method of Wolff, as practiced in the laboratory of the Bureau of Chemistry of the U. S. Department of Agriculture, has given very concordant results. Five determinations made on a sample of vegetable soil with the Wolff cylinders, which were weighed at intervals of 10, 20 and 30 days, gave the following results:

No. 1.	Water absorbed after 10 days.....	106.25	per cent.
" 2.	" " " " "	105.68	" "
" 3.	" " " " "	105.86	" "
" 4.	" " " " "	106.11	" "
" 5.	" " " " "	105.83	" "
Mean.....		105.95	" "
No. 1.	Water absorbed after 20 days	106.44	per cent.
" 2.	" " " " "	105.98	" "
" 3.	" " " " "	106.56	" "
" 4.	" " " " "	106.52	" "
" 5.	" " " " "	106.38	" "
Mean.....		106.38	" "
No. 1.	Water absorbed after 30 days.....	108.35	per cent.
" 2.	" " " " "	107.60	" "
" 3.	" " " " "	108.32	" "
" 4.	" " " " "	107.86	" "
" 5.	" " " " "	107.87	" "
Mean.....		108.00	" "

The data obtained show that there was only a slight increase in the amount of moisture absorbed after the tenth day.

As will be seen, however, from the following data, the soil within the cylinder does not contain in all parts the same percentage of moisture, the lower portions of the cylinder containing notably larger proportions than the upper parts. The cylindrical soil col-

umn was divided into four equal parts and the moisture determined in each part. Beginning with the top quarter the percentages of moisture are as follows:

First quarter.....	97.52 per cent.
Second "	105.91 " "
Third "	112.83 " "
Fourth "	116.48' " "

163. Method of Petermann.—The method of Wolff as practiced by the Belgin Experiment Station, at Gembloux, is essentially the same as described above.¹⁷

Peterman recommends the use of tared cylinders from 20 to 25 centimeters long and from six to eight centimeters in diameter. The cylinder is to be filled with the fine earth, little by little, with gentle tapping after each addition. The bottom of the cylinder is closed with a perforated rubber stopper on which is spread a moistened disk of linen. The cylinder, thus prepared and filled, is weighed and afterwards placed in a vessel containing distilled water, to such a depth as to secure a water level about two centimeters above the lower surface of the soil in the cylinder. The level of the water is kept constant as the contents of the cylinder are moistened by capillarity. When the earth appears to be thoroughly moistened, as can be told by the appearance of the upper surface, maintain the contact with water for about five or six hours.

The cylinder is then removed, the upper surface covered to avoid evaporation, allowed to drain for a few hours, wiped and weighed. The cylinder is again placed in water to see if any increase in weight takes place. The weight of the fine earth and of the absorbed water being known, the percentage of absorption is easily calculated.

164. Method of A. Mayer.—A glass tube, one and seven-tenths centimeters in diameter, composed of two pieces, 75 centimeters and 25 centimeters in length, is united by a piece of rubber tubing.¹⁸ The lower free end of the 75 centimeter piece is closed with a piece of linen. The tube is filled, with

¹⁷ *Analyse du Sol*, 13.

¹⁸ *Landwirtschaftliche Jahrbücher*, 8 : 771.

gentle jolting, with fine earth, the earth column thus extending 25 centimeters above the point of union of the two pieces. Thus prepared, a quantity of water is poured into the upper tube sufficient to temporarily saturate the whole of the soil in the short part of the tube.

During the sinking of the water in the tube there is thus effected a moistening of the material before it is wholly filled with water. After waiting until the free water poured on the top has disappeared the tube is separated at the rubber tube connection and a sample of the moist soil removed at that point. This is at once weighed and then dried at 100°. The loss in weight gives the water absorbed.

The number thus obtained is calculated to the standard by volume, by use of the number representing the apparent specific gravity of the fine earth.

For sand of different degrees of fineness the following numbers were found:

Degree of fineness.....	2	3	4
Per cent. water absorbed	7.0	13.7	44.6

The numbers thus obtained are taken to represent the absolute water capacity of a mineral substance in powder.

The full water capacity, *i. e.*, the power of holding water when the powder is immersed in water, the excess of which is then allowed to flow away is much greater than the absolute number.

This difference is shown in the following data:

	Quartz, size three.	Clay, size three.
Full water capacity.....	49.0 per cent.	46.8 per cent.
Absolute water capacity.....	13.7 " "	24.5 " "

In general the absolute is markedly inferior to the full water capacity. Only in the finest dust do the two numbers approach each other.

165. Volumetric Determination.—A convenient apparatus for this determination has been devised by Fuelling, formerly of the Chemical Division, Department of Agriculture. It is shown in Fig. 23.

It consists of an ordinary percolator the diameter of which decreases slightly towards the lower end, a thick-wall rubber tube

and an ordinary burette, divided in tenths. A rubber stopper is fitted to the mouth of the percolator and perforated twice, in the middle and at the side, the former for a small tube provided with

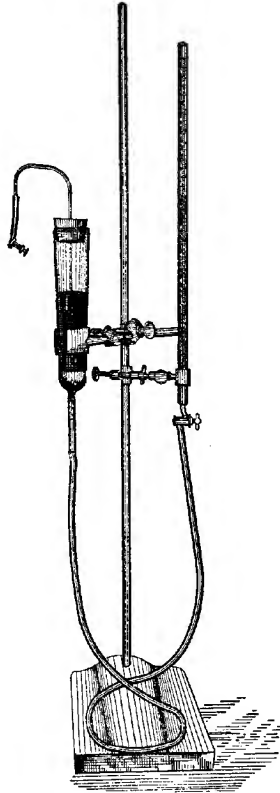


FIGURE 23.
FEULLING'S APPARATUS.

pinch-cock and the latter for the neck of a small funnel. The whole is supported on a convenient stand, the clamp holding the percolator being placed above that supporting the burette, both clamps arranged to slide on the stand-rod.

The method of manipulation is as follows:

A mark is placed upon the projecting tube at the lower end of the percolator, and the tube at this point may be drawn out sufficiently to decrease the width of meniscus to one-eighth inch. Into the percolator is first introduced a small disk of wire gauze or perforated porcelain. Fine shot No. 20 is poured into the percolator to the depth of 2 centimeters and then an equal depth of fine sand which has been previously digested with hydrochloric acid and well cleaned of dust by washing. Through the rubber stopper a small glass tube is passed and its lower end pressed firmly upon the gauze or porcelain disk, its upper end being curved and supplied with a pinch-cock.

The zero.—After the shot and sand have been shaken even, the burette is filled with water and raised above the level of the sand, wetting the percolator for four inches of its length. The burette is lowered and the shot and sand bed allowed to drain by opening the pinch-cock of the inner tube. The burette is raised and the shot-sand flooded repeatedly until, by lowering the burette until the zero mark of the percolator tube is reached, a uniform reading on the burette is secured. Thus the shot-sand bed is completely charged with water. The water level is now made zero on the percolator stem, the burette filled to its zero mark and the apparatus is prepared for the introduction of the soil.

The Determination.—The burette is raised until the water level is three inches above the sand, and the soil gently dropped through a funnel into the water. When the soil has been introduced and wetted completely the water level is raised above the soil and allowed to remain thus two hours. The burette is then lowered and the water allowed to drain from the wetted soil. From four to six hours are usually given for draining. The reading is taken on the burette after establishing the zero on the percolator stem, and the volume of absorbed water thus ascertained.

Example:

Water required to saturate disk, etc.....	1.50 cubic centimeters.
Weight of air-dried soil.....	20.00 grams.
Moisture at 105° therein.....	14.25 per cent.
Weight of dry soil.....	17.15 grams.
Weight of water in soil.....	2.85 grams.

Reading of burette after saturation.....	10.75 cubic centimeters.
Deduct water required for disk, etc., 1.50.....	9.25 " "
Temperature.....	20°.00
Deduct weight of 9.25 cubic centimeters H ₂ O at 20°.....	9.22 grams
Per cent. of water retained by soil.....	70.37
Weight " " " " ".....	12.07. grams

For general analytical work the correction for variations in the weight of water for different temperatures is of no practical importance. It is better to use the soil in the air-dried state and determine the water therein in a separate portion. Heating a soil to 105° materially alters its texture and the solubility of some of its constituents.

166. Accuracy of Results.—A sample of soil from the beet sugar station, in Nebraska, gave the following duplicate results:

First trial.....	45.75 per cent. water.
Second trial.....	44.85 " " "

Vegetable soils from Florida, containing varying proportions of sand, gave the following numbers for duplicate determinations:

Soil No.	First Trial.	Second Trial.
1	144.85 per cent.	145.43 per cent.
2	109.13 " "	107.93 " "
3a	46.86 " "	46.51 " "

a very sandy.

167. Method of Wollny.—A glass tube is made of a series of separate tubes properly joined together.¹⁹ Each tube is 15 centimeters long and four centimeters internal diameter and carries at each end a short cemented metal end piece having a flattened rim 1.5 centimeters broad. The single tubes are joined together by clamps. The lower end of the tube is closed with a strong piece of coarse linen. The soil to be examined is then filled in little by little, with gentle tamping.

On the upper end two glass tubes are placed, each ten centimeters long and four centimeters internal diameter. These tubes are furnished at each end with cemented brass cylinders which are expanded to a circular, evenly ground rim, 1.5 centimeters wide, also at right angles to the axis of the main tube. These

¹⁹ Forschungen auf dem Gebiete der Agricultur-Physik, 1885, 1886.

rims are greased and placed together, one on the other, and held together by wooden clamps.

The short glass tube in immediate connection with the main tube is also firmly filled with the soil sample to the depth of 4 centimeters, so that any settling which may take place in the soil on the addition of water may still find the main glass tube full of the sample. The volume of each of the component tubes before beginning the experiment is measured by the volume of water it contains.

The empty part of the upper glass tube is now filled with water and additional quantities of water are added from time to time until the soil is saturated. The lower end of the main tube is set on a glass plate to prevent evaporation.

As soon as the water shows itself at the lower end of the main tube, the excess of water in the upper glass tube is at once removed by a pipette and a stopper inserted through which a glass tube passes drawn out into a fine point above. The object of this is to avoid evaporation on the upper surface. The apparatus is then left at rest 36 hours. During this time which is necessary in order that all the excess of water may be removed by drainage, loss from evaporation may occur if the upper end of the tube be left open. To avoid this a stopper with capillary opening should be inserted. A tight stopper is not advisable by reason of the partial vacuum which would be formed by the flow of water.

At the end of this time the clamps are removed and the column of moist earth cut with a piece of platinum foil, and the two ends of each separated tube covered with glass plates. It is then weighed and the weight of moist earth determined by deducting the weight of the tube and its glass covers. The moist earth is carefully removed to a large porcelain dish and dried at 100°. After weighing the sample it is allowed to stand 24 hours in the air and reweighed to determine the moisture carried in the air-dry state. The data obtained may also be used to calculate the water content to volume per cent. since the volume occupied by the soil is known from the calibration of the tube. It is shown by these experiments that the water content in soil under the condi-

tions of time and drainage described increases from top to bottom. The difference between the water content of the upper and lower portions is less as the soil particles are finer. The quantity of water which a given volume of soil retains increases with the fineness of the particles.

168. Method of Heinrich.—The soil to the depth turned by the plow is dug out and in the hole a thin lead cylinder without bottom, 20 centimeters in diameter and 40 centimeters high, is placed.²⁰ The soil is then thrown back around and outside the cylinder until the latter appears buried in the ground.

The rest of the soil is passed into the vessel, through a sieve having four meshes to the centimeter, using for this purpose enough water to thoroughly moisten it. Care should be taken not to use enough water to cause any separation of the fine from the coarse particles.

By this process all coarse stones, sticks, etc., are separated. In sandy soils the cylinder is left for a few hours while in clay soils a much longer time is necessary. When the excess of water has disappeared the cylinder is removed, and a disk cut out of the center of it and dried at 100°.

169. Effect of Pressure on Water Capacity.—The decreasing capacity of soil to hold water developed by shaking or pressure, is determined by Henrici in the following way:²¹

Into a glass cylinder of 20 millimeters internal diameter are poured 20 cubic centimeters of water. A given quantity of soil is next added, and after standing until thoroughly saturated, the residual water is measured by pouring off, or better, by graduations on the side of the tube. The increase in the volume of the clear water is also measured, after shaking, in the same way. The data of a determination made as above described follow:

Water in cylinder.....	30	cubic centimeters.
Water and saturated soil	40	" "
Volume of unsaturated soil = e =	10	" "
Volume of saturated soil = $e + w$ =	20.5	" "
Water contained therein = w =	10.5	" "

²⁰ Forschungen auf dem Gebiete der Agricultur-Physik, 1885, 259.

²¹ Poggendorf's Annalen, 129 : 437.

By repeated shaking the volume of $e + w$, the content of w therein, and the relative values of $\frac{e}{w}$ were found to be as follows ;

	Cubic centimeters.	Cubic centimeters.	Cubic centimeters.	Cubic centimeters.
$e + w$	20.5	16.0	15.7	15.0
w	10.5	6.0	5.7	5.0
$\frac{w}{e}$	1.05	0.60	0.57	0.50

If e' represent the volume of the saturated soil then $e' = e + w$, and this gives the relation to the volume of dry earth represented by the equation $\frac{e'}{e} = 1 + \frac{w}{e}$. This indicates that the relative volume of the saturated soil is equal to unity increased by the relative content of water.

170. Coefficient of Evaporation.—At an ordinary room temperature in the shade, samples of soil, if they are subjected to examination in tolerably thin layers have nearly an equal coefficient of evaporation. That is, the absolute quantity of water evaporated in a given time is almost entirely conditioned upon the magnitude of the surface exposed and the temperature and saturation of the surrounding air. Only when exposed in conditions as nearly as possible natural in thin layers to the alternate action of the sunlight and shade do the soils show their peculiarities in respect of the evaporation of moisture. In order to ascertain these peculiarities, samples of soil which have been previously examined must be subjected to re-examination at the same time with the soil whose properties are to be determined.

A zinc box is used which should be protected with a well-fitting cover of thick paper, and the different samples of soil which are to be tested placed therein. This should now be placed in a wooden box, the top of which is exactly even with the top of the zinc vessel. This box containing the vessel is exposed to the sunlight. After 24 hours the zinc box can be taken away and its loss in moisture determined, and these weighings, according to the condition of the atmosphere, can be con-

tinued from 14 days to 3 weeks, the temperature of the air of course being carefully determined at each time. At first, all of the different soils being saturated with moisture, it will be observed that the loss of moisture is proportionately the same for all. Soon, however, the rapidity of the evaporation in the samples of soil rich in humus and clay will be decreased as compared with the sandy soils, and in general, those which possess a high capillary power capable of bringing the moisture rapidly from the deeper layers to the surface. There soon comes a point when the difference in evaporation is at its greatest; and then there will be a gradual diminution until the samples lose no further moisture. This point, for the different soils, can be determined by frequent weighings of the vessel.

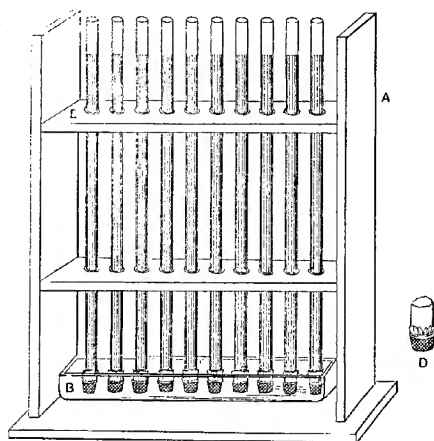


FIGURE 24.
APPARATUS TO SHOW CAPILLARY ATTRACTION OF
SOILS FOR WATER.

171. Determination of Capillary Attraction.—Long glass tubes graduated in centimeters may be used for this determination, or plain tubes so arranged as to admit of easy measurements with a rule. The tubes may be from one to two centimeters internal diameter and about one meter long. The fine earth should be evenly filled in little by little, with gentle jolting. The lower end

of each tube, before filling, is closed with a piece of linen, which is held in place by a rubber ring, as shown in D Fig. 24.

The tubes, after filling, are supported in an upright position by a frame AE, in a vessel B containing water in which the linen covered ends D dip to the depth of two centimeters.²² The height of the water in the several tubes should be read or measured at stated intervals. The water contained in the supply vessel should be kept at a constant height by a Mariotte bottle.

The observations may be discontinued after 24 hours, but even then the water will not have reached its maximum height.

It is recommended by some experimenters to cut the tubes after the above determination is completed, into pieces 10 centimeters in length, and to determine the per cent. of water in each portion.

172. Statement of Results.—The following table illustrates a convenient method of tabulating the observed data as given by König:²³

Number of sample.....	1	2	3	4	5	6
24 hours.	27.3	38.0	16.7	36.3	8.0	28.8 centimeters.
Height of 48 "	35.9	50.8	24.6	49.2	11.9	40.5 "
moisture col- 72 "	41.5	59.5	30.0	57.9	15.2	49.1 "
umn after: 96 "	44.4	66.2	33.5	63.8	17.5	55.2 "
120 "	46.7	70.0	36.3	68.5	19.2	60.5 "

173. Descending Capillarity.—In tubes filled with fine earth, as described above, water is quickly poured, the same quantity into each tube of the same diameter, or such quantities in tubes of different diameters as would form a water column of the same depth over the surface of the sample. The rate at which the water column descends in each tube, the time of the disappearance of the water at the surface and the final depth to which it reaches, are the data to be entered.

174. Statement of Results.—The points to be observed in the determination of descending capillarity are the number of hours required for the total absorption of a column of water of a given height, the depth of the moisture column at that moment, and the

²² Wahnschaffe, Anleitung zur Wissenschaftlichen Bodenuntersuchung, 143.

²³ Untersuchung landwirtschaftlich und gewerblich Wichtiger Stoffe, Second Edition, 56.

total depth to which the moisture column finally reaches. The data of observations with six samples with a water column four centimeters high are given by König as follows:²⁴

Number of sample.....	1	2	3	4	5	6
Number of hours required for water to disappear...	4.3	1.8	10.0	3.9	21.0	4.3
Depth of moisture at time of disappearance of water	11.0	12.0	11.4	13.3	11.7	12.0 centimeters.
Total depth of moisture....	13.0	18.1	13.0	19.0	12.0	16.5 "

175. Determination of the Coefficient of Evaporation.—The coefficient of evaporation is the number of milligrams of water evaporated from a square centimeter of soil surface in a given unit of time. It is evident that this number will vary with the physical state of the soil, the velocity of the wind, the saturation of the air with aqueous vapor and the temperature. In all statements of analyses these factors should appear.

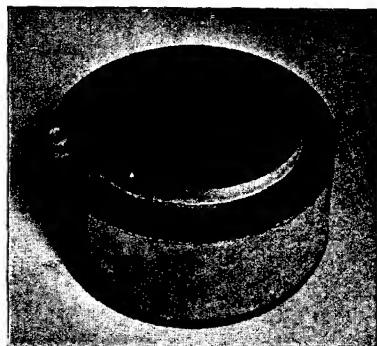
The process may be carried on first (a) with soil samples kept continually saturated with water and (b) with samples in which the water is allowed to gradually dry out.

Method a.—The determination may be made in the shade or sunlight.

In the Shade.—A zinc cylinder (Z, Fig. 25), 15 centimeters in diameter and 7.5 centimeters high, with a rim one centimeter wide and one centimeter from top, is covered at one end with linen or cotton cloth and filled with fine earth, with gentle jolting, until even with the top. It is then placed in a zinc holder H, into the circular opening of which it snugly fits as in A. This holder is 20 centimeters in diameter and 7.5 centimeters deep. It has an opening at O through which water can be added until it is filled so as to wet the bottom of Z when in place. As the water is absorbed by the soil more is added and, the top being covered, the apparatus is allowed to stand for 24 hours. At the end of this time the soil in the zinc cylinder is saturated with water to the fullest capillary extent.

The whole apparatus, after putting a stopper in O, is now weighed on a large analytical balance and placed in an open

²⁴ Untersuchung landwirtschaftlich und gewerblich wichtiger Stoffe
Second Edition, 57.



H Z
FIGURE 25.
APPARATUS FOR DETERMINING COEFFICIENT OF EVAPORATION.

room, with free-air circulation, for 24 hours. At the end of this time it is again weighed and the loss of weight calculated to milligrams per square centimeter. Where large and delicate balances can not be had, the apparatus can be constructed on a smaller scale suitable for use with a balance of the ordinary size.

In the Sunlight.—The apparatus described above is enclosed in a wooden box having a circular opening the size of the soil-zinc cylinder. In the determination of the rate of evaporation, the apparatus, charged and weighed as above described, is exposed to the sun for a given period of time, say one hour. On the second weighing the loss represents the water evaporated. The time of year, time of day, velocity of wind and temperature, and degree of saturation of the air with aqueous vapor, should be noted. The data obtained can then be calculated to milligrams of water per square centimeter of surface for the unit of time.

Method b.—As in method *a* the determination may be made in the shade or in the sunlight. The rate of evaporation is, in this method, a diminishing one and depends largely on the reserve store of water in the sample at any given moment.

The same piece of apparatus may be used as in the determinations just described. After charging the sample with moisture all excess of water in the outer zinc vessel is removed and the rate of evaporation determined by exposure in an open room or in the sunlight, as is done in the operations already described.

Alternate Method.—The zinc cylinders used in determining saturation coefficient, may also be employed in determining the rate of evaporation. Each cylinder should be wrapped with heavy paper or placed in a thick cardboard receptacle, and all placed in a wooden box, the cover of which is provided with circular perforations, just admitting the tops of the cylinders, which should be flush with the upper surface of the cover.

Arranged in this way the cylinders previously weighed are exposed in the shade or to direct sunlight and reweighed after a stated interval. On account of the small surface here exposed in comparison with the total quantity of soil and moisture it is recommended to weigh the cylinders once only in 24 hours. The weighings may be continued for a fortnight or even a month.

In soils fully saturated with water the rate of evaporation is at first nearly the same on account of the surface being practically that of water alone. As the evaporation continues, however, the rate changes markedly with the character of the soil.

176. Method of Wolff.—In order to expose a larger surface to evaporation and to secure the results in a shorter period of time, Wolff fills cubes of 6 cm. sides made of wire-gauze, with fine earth, and weighs and suspends them in the laboratory near a window and near the balance.²⁵ The wire-gauze bottoms and sides are previously covered with filter paper to prevent loss of soil. The soil in the cubes may also be completely saturated with water and the rate of evaporation determined as just described.

177. Estimation of Water Given up in a Water-Free Atmosphere.—The air-dried sample, in quantities of from 5 to 10 grams in a thin layer on glass, is placed over a vessel containing strong sulfuric acid. It is then placed on a ground glass plate and covered with a bell jar. The sample is weighed at intervals of five days until the weight is practically constant.

This method is valuable in giving the actual hygroscopic power of a soil depending on its structure alone.

178. Estimation of the Porosity of the Soil for the Passage of Gases.—Some further notion of the physical state of the soil known as porosity, may also be derived by a study of the rate at which it will admit of the transmission of gases, as shown in 160. Another method for estimating this has been devised by Ammon.²⁶

Air is compressed in two gas holders by means of a column of water of proper height to give the pressure required.

The tubes through which the air passes out of the gas holders are each furnished with a stop-cock and united with a glass tube having a side tube set in at right angles for carrying off the air.

The use of two holders makes it possible to carry on the experiment as long as may be desired, one holder being filled with air while the other is emptying. The common conducting tube is joined with a meter which is capable of measuring, to 0.01, the

²⁵ *Landwirtschaftliche Jahrbücher*, 2 : 381-3.

²⁶ *Forschungen auf dem Gebiete der Agricultur-Physik*, 1880, 211, 218.

volume of air passing through it. The pressure is regulated by means of the stop-cocks. The air passing from the meter is received in a drying tube filled with calcium chlorid. From the drying tube the air enters a drying flask filled below with concentrated sulfuric acid and above with pumice stone saturated therewith. Next the dried air passes through a worm, eight meters long, surrounded with water at a given temperature. The dried air thus brought to the desired temperature next enters the experimental tube. This tube is made of sheet zinc 125 centimeters in length and five centimeters in internal diameter. It is placed in an upright position, and about six centimeters from its upper end carries a small tube at right angles to the main one for connection with a water-filled manometer.

The upper and lower ends of the tube are closed with perforated rubber stoppers carrying tubes for the entrance and exit of the air.

In the inside of the zinc tube are found two close-fitting but movable disks, of the finest brass wire gauze, between which the material to be experimented upon is held.

The layer of fine soil is held between these disks and may be of such a depth as is required for the proper progress of the experiment. With soils of firm texture opposing a great resistance to the passage of the air the column of earth tested should be shorter than with light and very permeable soils. The experimental tube is surrounded with a water jacket, which may also be made of sheet zinc, carrying small tubes directed upwards for holding thermometers. The water jacket should be kept at the same temperature as the air which is used in the experiment.

The process of filling the tube, the amount of pressure to be used and the air and soil temperature, will naturally vary in different determinations.

The volume of air at a given pressure and temperature which passes a column of soil of a given length in a unit of time will give the coefficient of permeability.

179. Determination of Permeability in the Open Field.—A method for determining the rate of transmission of a gas through the soil in the field has been devised by Heinrich.²⁷

²⁷ Beurteilung der Ackerkrume, 222.

A box C (Fig. 26) is made of strong sheet iron and has an opening below, 10 centimeters square, and a height of about 20 centimeters. At exactly 10 centimeters from the bottom, the box has a rim at right angles to its length so that it can be placed only 10 centimeters deep in the soil. The box holds a volume of earth equal to 1,000 cubic centimeters.

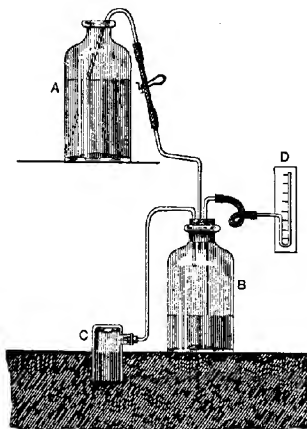


FIGURE 26.
METHOD OF HEINRICH.

The part of the box above ground is connected with the bottle B by a glass tube as indicated in the figure. The bottle B should have a capacity of about 10 liters. The air in B is forced out through C by water running in from the supply A and the pressure in B is recorded by the manometer D. The experiment should be tried on a soil thoroughly moist.

In measuring the pressure in B the water pressure should be cut off by the pinch-cock between A and B, and the pressure on the manometer observed after the lapse of one to two minutes.

MOVEMENT OF WATER THROUGH SOILS: LYSIMETRY

180. Porosity in Relation to Water Movement.—The intimate relation which water movement in a soil bears to fertility makes highly important the analytical study of this feature of porosity.

A soil deficient in plant food, in so far as chemical analysis is concerned, will produce far better crops when the flow of moisture is favorable than a highly fertile soil in which the water may be in deficiency or excess.

Aside from the actual rain-fall the texture of the soil, in other words its porosity, is the most important factor in determining the proper supply of moisture to the rootlets of plants. Even where the rain-fall is little, a properly porous soil in contact with a moist subsoil will furnish the moisture necessary to plant growth. This fact is well illustrated by the beet fields in Chino Valley, California. In this locality crops of sugar beets are produced without irrigation and almost without rain.

181. Methods of Water Movement.—The translocation of soil water is occasioned in at least two ways; namely,

1. By changing the porosity of a given stratum of soil.
2. By changing the amount of water a given stratum contains.

The following experiment by King illustrates a convenient method of studying this movement of water.²⁸

On fallow ground of light clay soil, underlaid at a depth of eighteen inches by a medium-grained sand, water, to the amount of two pounds per square foot on an area of eight by eight feet, was slowly added with a sprinkler, samples of soil having been previously secured in six-inch sections down to a depth of three feet. The samples were taken along a diagonal of the square under experiment and one foot apart, the middle sample of the line being from the center of the area. The sampling and wetting occurred between one and three P. M., on July 22d, and on the evening of the 23d a corresponding series of samples was taken along a line parallel to the first but eight inches distant. The changes in the percentages of water in the soil are given in the following table, showing the translocation of water in soil due to wetting the surface:

Inches.	Per cent. of Water.		Difference	
	Before wetting.	After wetting.	In per cent.	In pounds per cu.
0-6...	14.00	22.23	+ 8.23	+ 2.873
6-12.....	15.14	15.71	+ 0.57	+ 0.199
12-18.....	16.23	15.75	- 0.48	- 0.213
18-24.....	17.70	16.92	- 0.78	- 0.347
24-30.....	16.76	14.41	- 2.35	- 1.032
30-36.....	15.51	15.21	- 0.30	- 0.132

²⁸ Wisconsin Experiment Station Seventh Annual Report, 134.

The figures given in the last column of the table are computed from the absolute dry weights of the upper three feet of soil as determined in a locality some rods from the place of experiment, and are therefore only approximations, but the error due to this cause is certainly small. It will be seen that while only two pounds of water to the square foot were added to the surface, the upper six inches contained 2.87 pounds per square foot more than before the water was added, and the second six inches contained 0.199 pounds more, and this too in the face of the fact that the evaporation per square foot from a tray sitting on a pair of scales close by, was 0.428 pound during the interval under consideration. Similar experiments were made by getting the samples of soil at 5.30 P. M. in one-foot sections down to four feet, at four equally distant places along the diagonal of a square six by six feet, and having the ground sprinkled. At the same time four similar sets of samples were secured on lines vertical to each of the sides of the square but four feet distant from them. The amount of water the soil contained was then determined, and at 11.30 A. M., 19 hours later, another series of samples was removed at points about four inches distant from the last and the amount of water determined with the result given below.

TRANSLATION OF WATER OCCASIONED BY WETTING THE SURFACE.

Depth of samples.	WET AREA.				AREA NOT WET.			
	Before wetting.		After wetting.		First samples.		Second samples.	
	Per cent. of water.	Pounds of water per cubic foot.	Per cent. of water.	Pounds of water per cubic foot.	Per cent. of water.	Pounds of water per cubic foot.	Per cent. of water.	Pounds of water per cubic foot.
0-12 inches	16.86	11.78	20.15	14.06	17.72	12.38	18.27	12.75
12-24 "	17.76	15.79	19.71	17.52	19.18	17.05	19.94	17.72
24-36 "	16.76	14.73	17.72	15.58	16.97	14.92	17.52	15.40
36-48 "	15.01	14.03	16.47	15.40	15.49	14.48	15.16	14.17
Averages	16.59	14.08	18.51	15.64	17.34	14.71	17.71	15.01
Total am't of water	56.33		62.56		58.83		60.04	
Amount of change			6.23				1.21	

The above data show sufficiently well the method of investigation to be pursued in studies of this kind.

182. Capillary Movement of Water.—The method of investigation proposed by King consists in getting samples of soil at intervals of one, two, three, or four feet in depth, and determining the amount of moisture in each in connection with the amount of rain-fall during the period.²⁹ The quantity of water contained in a given soil, at various depths and on different dates, is shown in the following table:

Depth in feet.	Date	Per cent. water	Pounds per cubic foot.	Increase or decrease. Pounds per cubic foot.
1	March 8th	24.33	16.98	.....
1	April 18th	22.37	15.61	—1.37
2	March 8th	15.80	14.05	.....
2	April 18th	21.64	19.24	5.19
3	March 8th	11.16	9.81	.....
3	April 18th	16.24	14.27	4.46
4	March 8th	7.87	7.36	.....
4	April 18th	11.19	10.46	3.10

The rain-fall during the interval was 4.18 inches, equal to 21.77 pounds per square foot.

183. Lateral Capillary Flow.—To determine the lateral capillary flow of water in a soil the following method, used by King, may be employed:³⁰

A zinc lined tray, six by six feet in area and eight inches deep, is filled with a soil well packed. In one corner of this tray a section of five inches of unglazed drainage tile, having its lower end broken and jagged, is set and the dirt well filled in round it. By means of a Mariotte bottle water is constantly maintained in the bottom of this tile, three-quarters of an inch deep, so that it will flow laterally by capillary action into the adjacent soil, the object being to determine the extent and rate of capillary flow laterally.

The water content of the soil is determined at the time of starting the experiment, on the circumferences of circles described with the tile as a center, the distance between the circles being one foot. At stated periods, usually at intervals of one day, the content of moisture is again determined at the same points. The investigations show that the lateral movement of water in the soil is not rapid enough to extend much beyond three feet in 31

²⁹ Wisconsin Experiment Station Seventh Annual Report, 139.

³⁰ Wisconsin Experiment Station Seventh Annual Report, 145.

days, for beyond that distance the soil was found to be drier than at the beginning of the experiment. A record is to be kept of the amount of water delivered to the soil by weighing the supply bottle at intervals, and the rates given at which the soil takes up the water in grams per hour and pounds per day. Also the amount of flow per square foot of soil section together with the mean daily evaporation should be noted. The mean flow per foot of soil section is computed on the assumption that the outer face of the zone of completely saturated soil is the delivering surface. In King's work this point, as nearly as could be determined, was 12 inches from the corner of the tray and hence the figures at best can only be regarded as approximations. The method of stating results is shown in the following table:

SHOWING THE RATE OF LATERAL, CAPILLARY FLOW OF
WATER IN CLAY LOAM.

Date.	No. of days.	Total mean, hourly flow, grams.	Total mean, daily flow, pounds.	Mean daily flow per square foot, pounds.	Mean daily, evaporation, pounds.
Jan. 28 to Feb. 2....	5	70.70	3.73	2.38	.....
Feb. 2-7	5	85.98	4.54	2.91	.....
Feb. 7-12	5	79.33	4.19	2.64	.....
Feb. 12-17....	5	79.41	4.19	2.64	0.598
Feb. 17-22	5	70.79	3.74	2.38	0.534
Feb. 22-28	6	59.89	3.16	2.01	0.451
Feb. 28 to March 6..	6	60.74	3.21	2.04	0.458
Mar. 6-13	7	60.37	3.14	2.00	0.448
Means.....	—	—	—	2.38	0.498

From this table it will be seen that the flow of water in the soil varied in rate, being slower during the first five days than in the succeeding 15 days. After 20 days the flow dropped again to the beginning rate and then fell below, but remained quite constant during the following 19 days. For the sake of uniformity in units of measure the daily quantity of flow should be given in kilograms when the hourly flow is given in grams.

184. Causes of Water Movement in the Soils.—The movement of water is due to two forces, *viz.*, gravitation and capillarity.

The mechanical and mathematical principles governing the movement of water in soils are discussed by Briggs.³¹ When the

³¹ Bulletin No. 10, Division of Soils, Dept. of Agriculture.

flow of water due to gravitation ceases a condition of equilibrium is established between the force of gravitation and the forces opposing it. According to Briggs there is no sharply-drawn line between these two quantities of water. The relative proportion depends, among other factors, upon the texture and structure of the soil, the surface tension of the soil water, the temperature, and the length of the column of soil considered. The importance of this last factor can be shown from the following considerations: Suppose we have 100 cubic inches of soil packed into 100 cubical boxes without bottom or top, each containing 1 cubic inch. Suppose the soil in each box to be saturated with water. There will be a free water surface at the top and at the bottom of each box. By means of forces existing in these surfaces the water in each cube is enabled to overcome the attraction of gravity, so that each cube is able to retain an amount of water equal to that necessary to produce saturation. In this case, therefore, there is no gravitation water. Suppose now that these cubical boxes are built up in a vertical column 100 inches high. The water surfaces previously existing at the top and bottom, respectively, of two cubes now disappear when one cube is placed on top of the other. Instead of having 200 surfaces as before, we now have only two surfaces, and they are called upon to support a column of water 100 times as high as before. This they are unable to do, and water begins to drip from the lower surface. This water, which was previously what we have termed capillary, now becomes gravitational in its nature, due simply to a change in the length of the column. If the water in the soil was held in vertical capillary tubes running throughout the length of the column the water in each tube would simply fall until the two surfaces were able to support the weight of the liquid. In the soil, however, we have a different condition. As the water begins to leave the upper part of the column new surfaces are developed *within* the soil. As the water continues to drain away, these surfaces become more efficient in a way which is easily explained, and finally there comes a time when the opposing force exerted by these surfaces is sufficient to balance the weight of the liquid and the drainage ceases.

185. Effects of Salts on Water Movement.—Since the effectiveness of capillarity in opposing gravitation is dependent largely on the surface tension of the aqueous soil solution the addition of fertilizers, by changing this tension, may influence in a marked degree the translation of water in the soil. According to Briggs any change in the surface tension of the soil moisture tends to bring about an adjustment of the water throughout the whole mass of soil. If the surface tension of the water in the upper layers of a soil is increased, water is drawn toward that point. Since the surface tension of most salt solutions is higher than that of water and the surface tension increases with the concentration of the solution, it might be expected that any salt used as fertilizer a solution of which has a high surface tension would increase the amount of water in the soil.

It must be remembered, however, that the surface tension of solutions is very greatly decreased by the addition of very small quantities of certain organic substances produced through the decomposition of vegetable matter. This action is especially marked where there are present substances of an oily nature which do not go into solution, but spread out over the surface in an extremely thin film. Owing to such substances being continually produced by the decay of organic matter, the surface tension of the soil moisture is kept very low and could be only slightly influenced by the addition of salts. The application of substances to the soil for the purpose of changing its water content through a change in the surface tension, would not therefore necessarily be productive of marked results, except as indicated below.

186. Effect of Salt Solutions on Soil Moisture.—The mineral fertilizers, as a rule, as has already been stated, increase the surface tension of water, while organic matters in solution decrease it. But it must not be forgotten in this connection that but little of the organic matter in the fertilizers employed for the experiment passes into solution. In general, the results of experiment are in harmony with the well known effect of magnesium, sodium, and potassium chlorids, and sodium nitrate, to make the soil more moist in dry weather, and the opposite effect is produced by the application of soluble organic matter.

187. Method of Preparing Soil Extracts.—The soil extracts used in determining surface tension may be prepared in different ways. A common method of procedure is as follows:

Ten grams of the soil are rubbed up with from 15 to 20 cubic centimeters of distilled water and allowed to stand for 24 hours with frequent stirring. Any fine particles not removable by a paper filter are neglected, although they may give a turbid appearance to the solution. The solution may be secured perfectly clear by filtering through porcelain.

188. Lysimetry.—The process of measuring the capacity of a soil to permit the passage of water and of collecting and determining the amount of flow and determining soluble matters therein is known as lysimetry. In general, the rate at which water will pass through a soil depends on the fineness and approximation of its particles. Water will pass through coarse sand almost as rapidly as through a tube, while a fine clay may be almost impervious to its transit. The study of the phenomena of filtration through soil, and the methods of quantitatively estimating them, are therefore closely related to porosity.

Two cases are to be considered, *viz.*: First, percolation through samples of soil prepared for the special purpose, and second, the passage of the water through soil *in situ*, whether it be virgin or cultivated.

The determination of the rate of flow through a soil in laboratory samples, gives valuable information in respect of its physical properties, while the same determination made on the soil *in situ*, has practical relations to the supply of moisture to growing plants, and the waste of valuable plant food in the drainage waters. The determination of the rate of flow of water through a small sample, disturbed as little as possible in its natural condition, is classed with the first divisions of the work, inasmuch as the removal of a sample of soil from a field, and its transfer to the laboratory, subjects it to artificial conditions, even if its texture be but little disturbed by the removal.

189. Measurement of Rate of Percolation in a Soil Sample.—In order to measure approximately the power of the soil for permitting the passage of water, a box, about 25 centimeters

high and having a cross section of about three centimeters square, has been recommended. Below, this box has a funnel-shaped end with a narrow outlet tube, which at its lower end is closed with cotton, in such a way that a portion of the cotton extends through the stem of the funnel. A little coarse quartz sand is scattered over the cotton and afterwards the funnel part of the apparatus filled with it. The sand and cotton are saturated with water and the apparatus weighed. The box is then filled with the fine sample of earth, with light tapping, until the depth of earth has reached about 16 centimeters. The apparatus, after the addition of the air-dried earth, is again weighed to determine the amount of earth added, and the soil is then saturated by the careful addition of water. After the excess of water has run down the funnel, the total quantity of absorbed water is determined by reweighing the apparatus and the total water-holding power of the soil is determined. There is carefully added, without stirring up the surface of the soil, a column of water eight centimeters high, making in all from 60 to 70 grams. The time is observed until the water ceases to drip from the funnel. The dripping begins immediately after the water is poured on and ceases as soon as the liquid on the surface of the soil has completely disappeared. On the repetition of this operation a longer time for the passage of the water is almost always required than at the first time. The experiment, therefore, must be tried three or four times and the mean taken.

190. Method of Welitschowsky.—The soil is placed in the vessel *a*, Fig. 27, which is cylindrical in shape and five centimeters in diameter.³² The lower end of the cylinder is closed with a fine wire-gauze disk and the upper end is provided with an enlargement for the reception of the tube *b*, which is connected to *a* with a wide rubber band. The lower end of the tube *b* is also closed with a wire-gauze disk. These tubes may be conveniently made of sheet zinc. The tube *b* carries on the side, at distances of 10 centimeters, small tubes of 15 millimeters diameter. On the opposite side it is provided with a glass tube set into a side tube near the bottom for the purpose of showing the height of the water.

³² Forschungen auf dem Gebiete der Agrikultur-Physik, 10 : 202.

The side tube carrying the water gauge is provided with a stop-cock as shown in the figure.

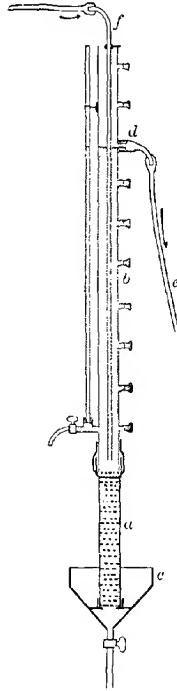


FIGURE 27.
METHOD OF
WELITSCHOWSKY.

In conducting the experiment, after the apparatus has been arranged as described, the small lateral tubes are, with one exception, closed with stoppers. On the open one, *d*, a rubber tube is fixed for the purpose of removing the water. The required water pressure is secured by taking the lateral opening corresponding to the pressure required. Water is introduced into the apparatus slowly through the glass tube *f*.

The water rises to *d* and then any excess flows off through *e*.

By a proper regulation of the water supply the pressure is kept constant at *d*. The water flowing off through *a* is collected by the funnel and delivered to graduated flasks where its quantity can be measured for any given unit of time. Since the rate of flow at first shows variations, the measurement should not be commenced until after the flow becomes constant.

In general, the experiments should last 10 hours, and, beginning with a water pressure of 100 centimeters, be repeated successively with pressures of 80, 60, 40 and 20 centimeters, etc., In coarse soils, or with sand, one hour is long enough for the experiment.

191. Statement of Results.—In the following tables the results for 90 centimeters, 70 centimeters, etc., are calculated from the analytical data obtained for 100 centimeters, 80 centimeters, etc.

Similar sets of data have been collected with powdered limestone, clay and humus.

The general conclusions from the experiments are as follows:

MATERIAL—QUARTZ SAND.

No. of Exp.	Diameter of sand particles in mm.	Water pressure in cm.	LITERS OF WATER PASSING IN TEN HOURS.		
			Thickness of Soil Layer.		
			10 cm.	20 cm.	30 cm.
1.	0.01—0.71.....	10	0.244	0.187	0.151
		20	0.282	0.198	0.154
		30	0.320	0.209	0.158
		40	0.358	0.220	0.161
		50	0.396	0.231	0.165
		60	0.434	0.242	0.168
		70	0.472	0.253	0.172
		80	0.510	0.264	0.175
		90	0.548	0.275	0.179
		100	0.586	0.286	0.182
2.	0.071—0.114.....	10	2.194	1.724	1.425
		20	2.898	2.012	1.578
		30	3.602	2.300	1.731
		40	4.306	2.588	1.884
		50	5.010	2.876	2.037
		60	5.714	3.164	2.190
		70	6.418	3.452	2.343
		80	7.122	3.740	2.496
		90	7.826	4.028	2.649
		100	8.530	4.316	2.802

1. Clay (kaolin) and humus (peat) are almost impermeable to water, and fine quartz and limestone dust are also very impermeable.

2. The permeability of a soil for water increases as the particles of the soil increase in size, and when particles of different sizes are mixed together the permeability approaches that of the finer particles.

3. The quantity of water passing through a given thickness of soil increases with the water pressure but is not proportional thereto, increasing less rapidly than the pressure.

4. The quantity of water passing under a given pressure is inversely proportional to the thickness of the soil layer when the particles are very fine and the pressure high.

192. Method of Whitney.—To determine the permeability of the soil or subsoil to water or air, as nearly as possible, in its natural condition in the field, Whitney uses the following method:—

A hole should be dug, and the soil and subsoil on one side removed to the depth at which the observation is to be made. A column of the soil or subsoil, two inches or more square, and four or five inches deep, is then to be carved out with a broad bladed knife, or a small saw can be conveniently used for cutting this out. A glass or metal frame, a little larger than the sample and three or four inches deep, is slipped over the column of soil, and melted paraffin is run in slowly to fill up the space between the soil and the frame. The soil is then struck off even with the top and bottom of the frame, preferably with a saw, or at any rate taking care not to smooth it over with a knife, which would disturb the surface and affect the rate of flow. The frame is then placed upon some coarse sand or gravel, contained in a funnel, to prevent the soil from falling out and to provide good drainage for the water to pass through. Another similar frame can then be placed on top and secured by a wide rubber band. A little coarse sand, which has been thoroughly washed and dried, is then placed on the soil, and water carefully poured on until it is level with the top of the frame. When the water begins to drop from the funnel more water must be added to the top, so as to have the initial depth of water over the soil the same in all the experiments. A graduated glass is then pushed under the funnel, and the time noted which is required for a quantity of water to pass through the soil. The quantity usually measured is equivalent to one inch

in depth over the soil surface. In getting the sample, root and worm-holes are to be avoided, and these are particularly troublesome in clay lands.

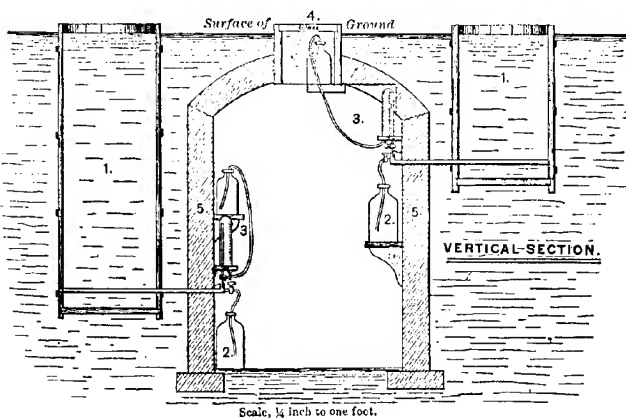
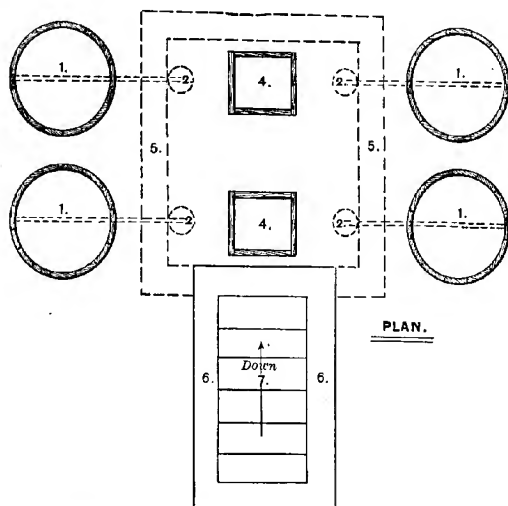
193. Measurement of Percolation Through the Soil in Situ.—If lateral translocation could be prevented, the measurement of the quantity of water descending in the soil through a given area would be a matter of simplicity. But to secure accurate results all lateral communication of a given body of soil with adjacent portions must be cut off. Various devices have been adopted to secure this result. An elaborate system of lysimetric measurements is illustrated by the data secured with the apparatus erected by the Agricultural Experiment Station, of Indiana.

The plan and section of the apparatus are shown in Fig. 28.

Each lysimeter box, when finished, resembles somewhat a hog's-head with one head. The sides, however, are perfectly straight inside, having a slight thickening in the center, for making them stronger. The sides and bottom of the apparatus are constructed of oak and lined with sheet copper carefully soldered so as to be water-tight. Six inches above, and parallel to the bottom of each of the boxes, is a perforated copper tube, which extends entirely across the lysimeter, and passing through one of the sides connects the box with an underground vault in which the observations are made. These tubes give an outlet to the drainage water, as described further on. The lysimeters are made of any required depth, the two which are shown in section being three and two-thirds and six and two-thirds feet deep, respectively.

The following method is employed for filling them with soil: There is first placed in the bottom of each tank a layer six inches deep of fine sand, sifted and washed, which fills them up to the level of the drainage tubes. The lysimeters are then filled with fine, sifted surface soil, to the depth of three and six feet, respectively, and leaving two inches of the boxes projecting above the surface of the soil so that each one will receive exactly its proper share of the rain-fall.

The tanks of the other pair, which are the same size as the first, are filled in a different way. The containers are placed over vertical columns of soil *in situ*, which are obtained by digging away all



Scale, $\frac{1}{4}$ inch to one foot.

FIGURE 28.

GROUND PLAN AND VERTICAL SECTION OF LYSIMETERS AND VAULTS SHOWING POSITION OF THE APPARATUS.

- | | |
|--------------------------------|----------------------------|
| 1, 1, 1, 1, Lysimeters. | 5, 5, 5, 5, Wall of vault. |
| 2, 2, 2, 2, Receiving bottles. | 6, 6, Brick walls. |
| 3, 3, Supplying apparatus. | 7, Entrance steps. |
| 4, 4, Skylights. | 8, Vault. |

the surrounding soil and leaving the columns standing. The shorter tank is sunk in this way to within two inches of its entire length. It is then tipped over carrying the column of soil with it. Six inches of the subsoil are then removed, when the drainage tube and sand are put in, as in the first pair, and the bottom of the tube soldered in place. The longer box is in the same way filled, as far as possible, with the soil in place, but a gravelly nature of the soil may render it impossible to do the filling with a single column unbroken, and in this case the gravel and sand from the lower portion of the soil may be filled in separately. The drainage tube and bottom of sand are placed in the longer tank in the same way as in the shorter.

The purpose of placing sand at the bottom of each container is to offer a porous stratum in which free water may collect and rise to the level of the perforated copper tube, which would prevent any further rise by conveying the surplus above into the vault as drainage water. The soil above the tube will therefore be constantly drained and the sand below constantly saturated, unless the water be drawn up by the capillary action of the soil as the result of evaporation from the surface.

By means of a proper arrangement within the vault, of a kind of mariotte bottle, the water may be caused to flow back through the drainage tube into the tank to take the place of that lost by evaporation, and thus maintain the level of free water just below the drainage tube. The water flowing back to the tank and the amount of drainage water, are carefully measured by a system of graduated tubes.

The lysimeters thus constructed represent tile-drained land; in one case the tile being three feet below the surface and in the other six feet below. The drainage waters collected in the receiving bottles can be measured and analyzed from time to time, as occasion may require, to determine the amount of plant food which is removed.

194. Improved Method of Deherain.—Deherain's earlier experiments were made in pots containing about 60 kilos of soil.³³ These vases serve very well for some kinds of plants, but there are other kinds which do not grow at all normally when their

³³ *Annales Agronomiques*, 16 : 337; 17 : 49; 18 : 237; 19 : 69.

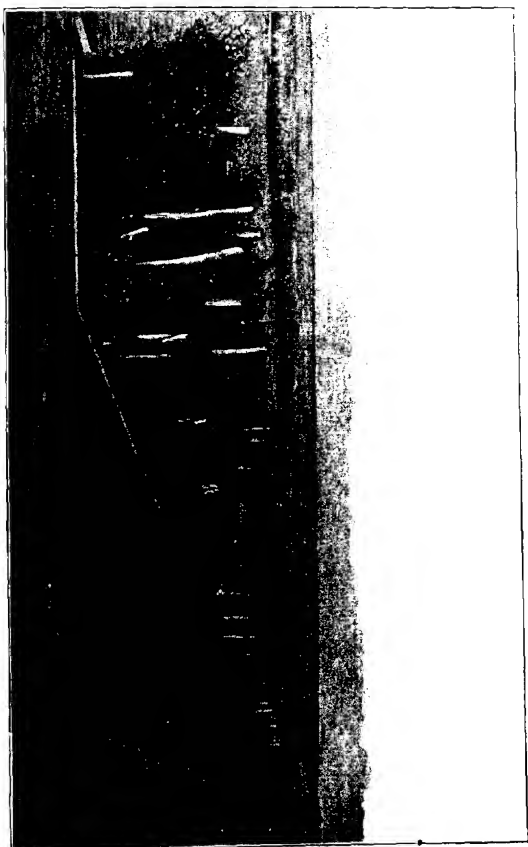


FIGURE 20.
DEERMAN'S APPARATUS FOR COLLECTING DRAINAGE WATER.

roots are imprisoned. For instance, in pots, even of the largest size, wheat is always poor, beets irregular, maize never acquires its full development, and the conclusions which can be drawn from the experiments can not be predicated of the action of the plant under conditions entirely normal.

It is necessary therefore to carry on the work in an entirely different way, and to construct boxes so large as to make the conditions of growth entirely normal. The arrangement of these boxes is shown in Fig. 29.

They are placed in a large trench, two meters wide, one meter deep, and 40 meters long. There are 20 boxes in this trench, the upper surface of each having an area of four square meters. The boxes are one meter deep, and therefore can contain four cubic meters of soil. The sides and bottoms of the boxes are made of iron lattice work, covered with a cement which renders them impervious to water.

The bottom inclines from the sides towards the middle, and from the back to the front, thus forming a gutter which permits of the easy collection of the drainage. The drainage water is conveyed, by means of a pipe and a funnel, into a demijohn placed in the ditch in front of the apparatus, as shown in the figure. These receptacles stand in niches under the front of the cases, and are separated by the brick foundations. Access to them is gained by means of the inclined plane shown in the figure, and this plane permits the demijohns in which the drainage water is collected, to be removed with a wheelbarrow for the purpose of weighing. This apparatus is especially suitable for a study of the distribution of the nitrogen to the crop, the soil and the drainage waters. The loss in drainage waters of phosphoric acid is insignificant in comparison with the loss in nitrogen and potash.

The boxes having been placed in position they are filled with the natural soil, to the depth of one meter, in such a way that the relative positions of the soil and subsoil are not changed.

While the soil is transferring to the boxes it is carefully sampled in order to have a portion representing accurately the composition of both the soil and subsoil. These samples are subjected to analysis and the quantities of nitrogen, phosphoric acid, and potash contained therein carefully noted.

One or two boxes should be left without crop or fertilizer to determine the relations of the soil and subsoil to the rain-fall, and three or four should be kept free of vegetation and receive treatment with different fertilizers in order to determine the influences of these on the deportment of the soil to rain-fall. The rest should be seeded with plants representing the predominant field cultures of the locality, and some of them should be fertilized with the usual manures used in farm culture.

195. IMPORTANCE OF ANALYSIS OF DRAINAGE WATERS.

Since certain mineral principles have been recognized as necessary to vegetation, much study has been given to the conditions of their assimilation. At first it was assumed that they cannot be absorbed except they become dissolved in the water of the soil. The memorable experiments of Huxtable and Thompson and of Way upon the absorbent properties of earths have modified this opinion, and several eminent savants, Liebig among others, have attributed to the roots the power to assimilate directly the alkalis and the phosphates precipitated upon the particles of arable soil. Quite a large number of experiments have been instituted upon this subject, especially in Germany, but there are few records of analyses of the solutions which are really found in the cultivated soils, analyses which seem however essential to the question under discussion. Schloesing is of the opinion that drainage waters, collected after having been filtered through a meter of earth, whose poverty has served for illustration, cannot faithfully represent the solution which the arable layer imbibes.³⁴ The lysimeters of Fraas and Zoeller, which give the drainage water from this layer, furnish some elements of discussion which are more useful but the soils give up their water only under certain conditions independent of the observer, and the lysimeters cannot possibly collect the solution existing at a given moment, at a given depth, under given conditions of temperature, and of condition of the atmosphere and of moisture. The method proposed by Schloesing to avoid these difficulties is described in part eighth.

³⁴ Comptes rendus, 70 : 94.

PART FOURTH

MECHANICAL ANALYSIS OF SOILS

196. Purpose of Mechanical Analysis.—By an optical mineral analysis of soils the investigator determines the character of the particles that can be seen with the eye or with the aid of the microscope. By a chemical analysis he determines the materials entering into the constitution of these particles. The object of mechanical analysis is to determine the size of the various mineral particles making up the bulk of the soil and to separate these particles into groups of approximately the same size. Such a separation throws light on the relation of the soil to moisture and permeability to the rootlets of plants, but gives no indication whatever of the quantity of plant food which the soil may contain.

197. General Principles.—The underlying principle in the mechanical analysis of soils is based on sifting or on sedimentation or, in other words, the rate at which segregated particles of soil will fall through a liquid medium, usually water. The larger particles and even the fine sand will rapidly sink while the smaller particles and the fine clays may remain in suspension for hours and days. Since the larger particles sink to the bottom too rapidly to admit of separation by sedimentation they must be separated into groups of any given size by sifting. Since the finest silt may remain in suspension for days and even weeks, it is usually determined by evaporation or by difference after having weighed all the larger classes of particles. Since much of the material of the larger particles, especially of lime particles, may pass into solution in the water used as a solvent this method of determination of the suspended particles is not strictly accurate. It is important in all cases that any flocculated material, that is small aggregates formed by the adhesion of smaller particles, be broken up as perfectly as possible into their constituent elements.

It is evident that should an upward movement in the liquid be

instituted equal in velocity to the natural descent of any particle in obedience to the impulse of gravity, that particle would remain *in situ* and all other particles having a less velocity of descent would be carried upward. Hence, it follows that the separation of the soil into group particles may also be effected by means of an upward current of water moving at successively increasing velocities.

In respect of the liquid in which the separation is effected water has been uniformly employed. By reason of its solvent action on many of the soil components, especially those in which lime and potash are found, its use is attended with certain difficulties. No other liquid, however, has been proposed to which fewer objections could be made. The ideal liquid is one that would exercise no solvent action, favor the disaggregation of the flocculated soil particles and permit the freest movement of the single particles.

Precedent to the separation of the particles of which a soil is composed into groups of approximately a given size, the removal of those parts of the soil of excessive fineness even beyond the power of microscopic identification becomes a necessity. Such particles approach a state of subdivision and freedom from methodical arrangement which characterize that class of gelatinous non-crystalline matters known under the general name of colloids.

198. Suspended Colloids.—The clay which remains in suspension in water for 24 hours or longer may be regarded as a colloid body in suspension. Such a body, as has been shown by experiment, remains in suspension only in the absence of an electrolyte in the solution or when an electrolyte is present in a certain minimal quantity. The suspension of these fine particles in the light of this theory is ascribed to an electrical static charge which may be either positive or negative. Thus water which carries any notable quantity of a soluble salt which plays the rôle of an electrolyte will not be capable of holding a clay in suspension for any length of time. When an electrolyte such as common salt, alum or a mineral acid is added to water carrying suspended clay the static charges are discharged or so modified as to permit of the coagulation and consequent subsidence of the colloid body. This

theory of clay suspension is in harmony with many of the well known results of treating such suspended matter both with electrolytes and non-electrolytes.

According to Noyes there are two classes of colloidal mixtures.³⁵

As types of these are cited aqueous solutions of gelatine and of colloidal arsenious sulphid. The one gelatinizes on cooling, the other does not.

The former is not coagulated by the addition of moderate amounts of salts, the latter is. The former class may be designated as colloidal solutions, the latter as colloidal suspensions, Strong electrolytes tend to cause coagulation in colloidal suspensions and the ion carrying the charge opposite to that borne by the suspended colloid is mainly responsible for the coagulation that takes place.³⁶

199. Effect of Adding Non-Electrolytes to Suspended Clay.—The progress of flocculation may be retarded by the addition of certain substances such for instance as ammonia to clay water. To be in harmony with the above theory such bodies should act in some way either to increase the static charge of the suspended particles or to diminish the power of an electrolyte to neutralize them. The efficiency of ammonia for this purpose has been studied by Briggs,³⁷ who has shown that ammonia has a very marked effect in breaking up the flocculations of the clay particles, and in increasing the quantity of the group approximately .005 millimeter, and below in diameter. This influence, however, is not apparent in strongly alkaline soils.

199*. Separation of Colloids from the Soil.—In the method of separating sand and clay by centrifugal action in a liquid heavier than water Sjollem has developed a method of separating the colloidal bodies in a state of approximate purity.³⁸

For the method of separation reference is made to a paragraph further along. (Paragraph 268).

³⁵ Journal American Chemical Society, 27 : 86.

³⁶ Noyes—Presidential Address—Journal American, Chemical Society, 27 : 85, et seq.

³⁷ Bulletin 24, Bureau of Soils, 22.

³⁸ Die landwirtschaftlichen Versuchs-Stationen, 1905 : 53, 70

For the microscopic examination of the separated colloid staining with an aqueous solution of methyl violet is recommended. Only the colloidal particles of the mass take the stain.

The colloidal matter prepared as described further along is subjected to analysis to determine its value for plant nourishment.

THE FLOCCULATION OF SOIL PARTICLES.

200. Relation of Flocculation to Mechanical Analysis.—The tendency of the fine particles of silt to form aggregates, which act as distinct particles of matter, is the chief difficulty connected with the separation of the soil into portions of equal hydraulic value by the silt method of analysis. This tendency has been discussed fully by Johnson³⁹ and Hilgard.⁴⁰

201. Illustration of Flocculation.—A sediment, consisting of particles of a water velocity equal to one millimeter per second, is introduced into an ordinary conical elutriating tube placed vertically, in which the current of water entering below performs all the stirring which the particles receive.

A current of water corresponding to a velocity below one millimeter per second will, of course, not carry any of the particles out at the top of the cylindrical tube, but will keep them moving through the conical portion of the tube. If now the current be increased until its velocity is greater than one millimeter per second after having run at the slower velocity for fifteen or twenty minutes, very little of the sediment will pass over, although theoretically the whole of it should. Even at a velocity of five millimeters per second, much of the sediment will remain in the tube. This, of course, is due to the coagulation of the particles into molecular aggregates having a higher hydraulic value even than five millimeters per second. These aggregates can be broken up by violent stirring or moderate boiling, and the sediment reduced again to its proper value. The conclusions which Hilgard derives from a study of the above phenomena are as follows:

1. The tendency to coagulation is, roughly, in an inverse ratio to the size of the particles. With quartz grains it practically

³⁹ Connecticut Agricultural Experiment Station, Annual Report, 1877.

⁴⁰ American Journal of Science, 1879 [3], 17 : 205.

ceases when their diameter exceeds about two-tenths of a millimeter having a hydraulic value of eight millimeters per second. The size of the aggregates formed follows practically the same law as above. Sediment of 0.25 millimeter hydraulic value will sometimes form large masses like snow-flakes on the sides of the elutriator tube.

2. The degree of agitation which will resolve the aggregates into single grains is inversely as the size of the particles; or, more properly perhaps, inversely as their hydraulic value.

3. The tendency to flocculation varies inversely as the temperature. So much so is this the case that Hilgard at one time contemplated the use of water at the boiling point in the mechanical analysis of soils, in place of mechanical stirring.

4. The presence of alcohol, ether, and of caustic or carbonated alkalis, diminishes the tendency to flocculation, while the presence of acids and neutral salts increases it.

5. As between sediments of equal hydraulic value, but different densities, the tendency to flocculation seems to be greater with the less dense particles.

In regard to the mechanical actions which take place between the particles, Hilgard considers them as irregular spheroids, each of which can at best come in contact at three points with any other particle. The cause of aggregation cannot therefore be mere surface adhesion independent of the liquid, and the particles being submerged there is no meniscus to create an adhesive tension.

Since experiment shows that the flocculative tendency is measurably increased by the cohesion coefficient of the liquid, it seems necessary to assume that capillary films of the latter interposed between the surfaces of solids create a considerable adhesive tension even in the absence of a meniscus.

202. Effect of Potential of Surface Particles.—Whitney suggests that this attraction is due to the potential of the surface particles of solids and liquids.⁴¹ The potential of a single water particle is the work which would be required to pull it away from the surrounding water particles and remove it beyond their sphere of attraction.

⁴¹ Bulletin 4, Weather Bureau, Department of Agriculture, 19.

For simplicity, it may be described as the total force of attraction between a single particle and all other particles which surround it. With this definition, it will be seen that the potential of a particle on an exposed surface of water is only one-half of the potential in the interior of the mass, as half of the particles which formerly surrounded and attracted it were removed when the other exposed surface of water was separated from it. A particle on an exposed surface of water, being under a low potential, will therefore tend to move toward the center of the mass where the potential, *i. e.*, the total attraction, is greater, and the surface will tend to contract so as to leave the fewest possible number of particles on the surface. This is surface tension.

If, instead of air, there is a solid substance in contact with the water, the potential will be greater than on an exposed surface of the liquid, for the much greater number of solid particles will have a greater attraction for the water particles than the air particles had. They may have so great an attraction that the water particle on this surface, separating the solid and liquid, may be under greater potential than prevails in the interior of the liquid mass. Then the surface will tend to expand as much as possible, for the particles in the interior of the mass of liquid will try to get out on the surface. This is the reverse of surface tension. It is surface pressure, which may exist on a surface separating a solid and liquid.

Muddy water may remain turbid for an indefinite time, but if a trace of lime or salt be added to the water the grains of clay flocculate, that is, they come together in loose, light flocks, like curdled milk, and settle quickly to the bottom, leaving the liquid above them clear. Ammonia and some other substances tend to prevent this and to keep the grains apart if flocculation have already taken place.

If two small grains of clay, suspended in water, come close together they may be attracted to each other or not, according to the potential of the water particles on the surface of the clay. If the potential of the surface of water is less than that of the particle in the interior of the mass of liquid, there will be surface tension, and the two grains will come together and be held with some

force, as their close contact will diminish the number of surface particles in the liquid. If, on the other hand, the potential of the particle on the surface of the liquid is greater than of the particle in the interior of the mass, the water surface around the grains will tend to enlarge, as there will be greater attraction for the water particles there than in the interior of the mass of liquid, and the grains of clay will not come close together and will even be held apart, as their close contact would diminish the number of surface particles in the liquid around them.

203. Influence of Surface Tension.—Hilgard supposes that the surface tension which is assumed to exist between two liquid surfaces must exert a corresponding influence between the surfaces of solids and liquids, apart from any meniscal action.

It is then to be expected that the adhesion of the particles constituting one of these floccules will be very materially increased whenever the formation of menisci between them becomes possible by the removal of the general liquid mass. Suppose one of the floccules to be stranded, it will, in the first place, remain immersed in a sensibly spherical drop of liquid. As this liquid evaporates, the spherical surface will become pitted with menisci forming between the single projecting particles, and as these menisci diminish their radius by still further evaporation, the force with which they hold the particles together will increase until it reaches a maximum. As the evaporation progresses beyond this point of maximum, the adhesion of the constituent particles must diminish by reason of the disappearance of the smaller menisci, and when finally the point is reached when liquid water ceases to exist between the surfaces, the slightest touch, or sometimes even the weight of the particles themselves, will cause a complete dissolution of the floccule, which then flattens down into a pile of single granules.

In regard to natural deposits from water, Hilgard supposes that they are always precipitated in a flocculated state. The particles of less than two-tenths millimeter diameter are carried down with those of a larger diameter having much higher hydraulic value. Thus the deposition of a pure clay can take place under only very exceptionable circumstances.

Whitney, on the other hand, suggests that grains of sand and clay carry down mechanically the particles of fine silt and clay as they settle in a turbid liquid in a beaker; and it is often difficult to wash out a trace of fine material from a large amount of coarse particles, for this reason, although there may be no trace whatever of flocculation.

204. Quincke's Theory.—Quincke presents an ingenious theory in regard to the flocculation of turbid solutions.⁴² His theory is that on the surface of the flocks, at least for a short time after their formation, oily, viscous fluid exists. In the case of kaolin, and probably other suspended silts from soils, this viscous fluid is supposed to be colloidal silicic acid. On the surface of separation of this oily fluid with the surrounding aqueous fluid, a surface tension acts and air bubbles are separated as in the limit of two heterogeneous fluids. Probably changes of the surface tension of the boundary of oily and aqueous fluid, and the periodical spreading of heterogeneous liquid, will excite vortices and join together the small suspended particles to form the flocks. In the case of kaolin turbidity, Quincke observed, after two months, a great many flocks adhering to the shadow side of the glass. Under the microscope the flocks showed threads or tubes of a downward flown liquid, with spheroidal enlargements or contractions. A sediment on the bottom of the glass cylinder had the appearance of solidified liquid, containing deformed bubbles and coherent foam cells, smooth spheres of .002 to .0004 millimeter in diameter, having greater refractive power than the neighboring particles. In this case, the particles of kaolin, as above assumed, have been covered by the influence of the water with an oily, viscous fluid, probably silica hydrate, on the surface of which another fluid has been spread out. The periodical spreading had combined the suspended kaolin particles in larger flocks which slowly sank to the bottom or were drawn by the vortices against the glass walls while the particles covered with oily fluid adhered.

If by the influence of light more spreading fluid is formed on the light side of the suspended particles than on the shaded side the suspended particles will go towards the light, that is, be posi-

⁴² Chemical News, 1901, 84 : 174.

tively photodromic. Under the contrary supposition, they would go to the shaded side or be negatively photodromic.

205. Destruction of Floccules.—The destruction of the natural floccules is seen in the ordinary process of puddling earth or clay. It is also the result of violent agitation of water or of kneading or boiling, or, finally, to a certain extent, of freezing. All these agencies are employed by the workers in clay for the purpose of increasing the plasticity which depends essentially upon the finest possible condition of the material to be worked. As an illustration of this, Hilgard cites the fact that any clay or soil which is worked into a plastic paste with water, and dried, will form a mass of almost stony hardness. If, however, to such a substance one-half per cent of caustic lime be added, a substance which possesses in an eminent degree the property of coagulating clay, the diminution of plasticity will be obvious at once, even when in a wet condition. If now the mass be dried, as in the previous case, it is easily pulverized. This is an illustration of the effect of lime upon stiff lands, rendering them more readily pulverulent and tillable. The conversion of the lime into a carbonate in the above experiment by passing bubbles of carbonic acid through the mass while still suspended in water does not restore the original plasticity, thus illustrating experimentally the fact known to all farmers that the effect of lime on stiff soil lasts for many years, although the whole of the lime in that time has been converted into carbonate.

206. Practical Applications.—The practical application of this is, according to Hilgard, that the loosely flocculated aggregation of the soil particles is what constitutes good tilth. For this reason the perfect rest of a soil, if it is protected from the tamping influence of rains and the tramping of cattle, may produce a condition of tilth which cannot be secured by any mechanical cultivation. As an illustration of this, the pulverulent condition of virgin soils protected in a forest by the heavy coating of leaves may be cited. On the contrary, as pointed out by Hilgard, there are some kinds of soil in which a condition of rest may produce the same effect as tamping. These are soils which consist of siliceous silt without enough clay to maintain them in position

after drying. In such a case, the masses of floccules collapse by their own weight or by the least shaking, and fall closely together, producing an impaction of the soil. This takes place in some river sediment soils in which the curious phenomenon is presented of injurious effects produced by plowing when too dry, which is the direct opposite of soils containing a sufficient amount of clay and which are injured by plowing too wet.

It is further observed that the longer a soil has been maintained in good tilth, the less it is injured by wet plowing. This is doubtless, due, according to Hilgard, to the gradual cementation of the floccules by the soil water which fixes them more or less permanently.

Whitney believes that the arrangement of the grains, or the condition of flocculation in the soil, or the distance apart of the soil grains, is determined, to a large extent, by the potential on the surface of the grains; and he suggests that by changing this the exceedingly fine grains of silt and clay can be pulled together or can be pushed further apart, and so alter the whole texture of the land.

The action of alkaline carbonates in preventing flocculation, and thus rendering tillage difficult or impossible, is pointed out by Hilgard in the case of certain alkali soils of California. The soils which are impregnated with alkaline carbonates are recognized by their extreme compactness. The suggestion of Hilgard to use gypsum on such soils has been followed by the happiest results. This gypsum tends to render phosphates insoluble, and thus prevents loss by drainage, and yet leaves the plant food in a sufficiently fine state to be easily available for absorption.

207. Suspension of Clay in Water.—The suspension of clay in water and the methods of producing or retarding flocculation and precipitation have also been studied by Durham.⁴³

In a number of tall glass jars fine clay is stirred with water, and the results of precipitation watched. In all cases it will be noticed that the clay rapidly separates into two portions, the greater part quickly settling down to the bottom of the jars, and the smaller part remaining suspended for a greater or less length of time.

⁴³ Chemical News, 1874, 30 : 57.

The power which water possesses of sustaining clay is gradually destroyed by the addition of an acid or salt; a very small quantity, for instance, of sulfuric acid, is sufficient to precipitate the clay with great rapidity. The ability to hold the clay in suspension in this case may be partially restored by neutralizing the acid. In solutions of sulfuric acid and sodium chlorid of varying strengths, suspended clay is precipitated in the order of the specific gravity of the solutions, the densest solutions being the last to clear up. This may be due to the greater viscosity of the denser liquids.

The power which water possesses of sustaining clay is gradually decreased by the addition of small quantities of certain salts and of lime.

208. Effect of Chemical Action.—Brewer⁴⁴ emphasizes the importance of chemical action in the flocculation of clays. As expressed by him the chemical aspects of the phenomena of sedimentation have either been lightly considered or entirely ignored. Brewer is led to believe that the action of clay thus suspended is analogous to that of a colloidal body. Like a colloid, when diffused in water, the bulk of the mass is very great, shrinking enormously on drying into a mass curiously like some organic colloids. He therefore concludes that clays probably exist in suspension as a series of hydrous silicates feebly holding different proportions of water in combination and having different properties so far as their behavior to water is concerned.

Some of them he supposes swell up in water much as boiled starch does, and are diffusible in it with different degrees of facility, and that the strata observed on long standing of jars of suspended clay represent different members of this series of chemical compounds which hold their different proportions of combined water very feebly and are stable under a very limited range of conditions.

These compounds are probably destroyed or changed in the presence of acids, salts and various other substances, and are stable only under certain conditions of temperature, those which exist at one temperature being destroyed or changed to other compounds at a different temperature.

⁴⁴ American Journal of Science, 1885, [3], 29 : 1.

209. Theory of Barus.—Brewer's hypothesis, however, is not in harmony with the demonstration of Barus, who proves that a given particle of clay has the same density in ether as in water.

The physical and mathematical aspects of sedimentation have also been carefully studied by Barus.⁴⁵ The mathematical conditions of a fine particle suspended in a liquid and free from the influences of flocculation are described by Barus in the following equations.

If P be the resistance encountered by a solid spherule of radius r , moving through a viscous liquid at the rate x , and if k be the fractional coefficient, then $P = 6\pi krx$. Again, the effective part of the weight of the particle is $P' = \frac{4}{3}\pi r^3 (\rho - \rho')g$, where g is the acceleration of gravity and ρ and ρ' the density of solid particle and liquid, respectively. In case of uniform motion $P = P'$.

$$\text{Hence } x = \frac{2}{9k} r^2 (\rho - \rho')g \dots \dots \dots (1).$$

In any given case of thoroughly triturated material the particles vary in size from a very small to a relatively large value; but by far the greater number approach a certain mean figure and dimension. An example of this condition of things may be formulated. To avoid mathematical entanglement let $y = Ax^2e^{-x^2} \dots \dots \dots (2)$ where y is the probable occurrence of the rate of subsidence x . If now the turbidity of the liquid (avoiding optical considerations) be defined as proportional to the mass of solid material particles suspended in unit of volume of liquid, then the degree of turbidity which the given ydx particles add to the liquid is *cacteris paribus*, proportional to r^3ydx , where r is the mean radius. Hence the turbidity, T , at the outset of the experiment (immediately after shaking), is $T = T_0 \int_0^\infty r^3ydx = T_0$, where equations (1) and (2) have been incorporated.

If the plane at a depth d below the surface of the liquid be regarded, then at a time after shaking the residual turbidity is

$$(3) \dots \dots T_d = T_0 \int_0^d r^3ydx = T \left(1 - \left[1 + \frac{d^2}{t^2} \right] e^{-\frac{d^2}{t^2}} \right)$$

The equation describes the observed occurrences fairly well.

The phenomena of stratification observed by Brewer are ex-

⁴⁵ American Journal of Science, 1889, [3], 37 : 122.

plained by Barus from the above formula: In proportion as the time of subsidence is greater, the tube shows opacity at the bottom, shading off gradually upward, through translucency, into clearness at the top. If, instead of equation (2), there be introduced the condition of a more abrupt maximum, if, in other words the particles be very nearly of the same size, then subsidence must take place in unbroken column capped by a plane surface which at the time zero coincides with the free surface of the liquid. Again, suppose one-half of the particles of this column differ in some way uniformly from the other half. Then at the outset there are two continuous columns coinciding, or, as it were, interpenetrating throughout their extent. But the rate of subsidence of these two columns is necessarily different, since the particles, each for each, differ in density, radius and frictional qualities, by given fixed amounts. Hence the two surfaces of demarcation at the time zero coincide with the free surface. In general, if there be n groups of particles uniformly distributed, then at the time zero n continuous columns interpenetrate and coincide throughout their extent. At the time t , the free surface will be represented by n consecutive surfaces of demarcation below it, each of which caps a column, the particles of which form a distinct group.

From a further discussion of the mathematical condition under which the subsidence of the particles takes place, Barus is of the opinion that Durham's theory of suspension being only a lower limit of solution is rapidly gaining ground, yet without being attended with concise experimental evidence which will account for the differences in the rate of subsidence. On the contrary, Brewer's hypothesis of colloidal hydrates is more direct and should be subjected to experimental proof. The test shows that the particles retain their normal density, no matter how they are suspended or circumstanced. Their density in ether and water in other words is nearly the same.

Further, in the explanation of the phenomenon of sedimentation, the following principle may be regarded as determined; namely, if particles of a comminuted solid are shaken up in a liquid, the distribution of parts after shaking will tend to take place in such a way that the potential energy of the system of

solid particles and liquid, at every stage of subsidence, is the minimum compatible with the given conditions.

According to Barus it is necessary, in order to pass judgment on the validity of any of the given hypotheses, to have in hand better statistics of the size of the particles relative to the water molecule, than are now available. Inasmuch as the particles in pure water are individualized and granular, it is apparently at once permissible to infer the size of the particles from the observed rates of subsidence. His observations show that the said rate decreases in marked degree with the turbidity of the mixture. Hence the known formulæ for single particles are not rigorously applicable, though it cannot be asserted whether the cause of discrepancy is physical or mathematical in kind. It follows that special deductions must be made for the subsidence of stated groups of particles before an estimate of their mean size can fairly be obtained.

Rowland⁴⁶ reaches a closer approximation for the fall of a single particle by showing that the liquid, even at a large distance from the particle, is not at rest.

In the case of water, however, it is noticed that despite the large surface energy of the liquid, subsidence takes place in such a way that for a given mass of suspended sediment the surfaces of separation are a maximum. On the other hand, in case of subsidence in ether or in salt solutions, the solid particles behave much like the capillary spherules of a heavy liquid shaken up in a lighter liquid with which it does not mix. In other words, the tendency here is to reduce surfaces of separation to the least possible value, large particles growing in mass and bulk mechanically at the expense of smaller particles; in other words, exhibiting the phenomenon of flocculation.

210. Practical Applications—The action of certain soluble mineral substances in promoting flocculence has been taken advantage of in later times in the construction of filters for purifying waters holding silt in solution. In these filters the introduction of a small quantity of alum, or some similar substance, into the water usually precedes the mechanical separation of the flocculent mate-

⁴⁶ Proceedings National Academy of Science, 1892.

rial. In the same way the action of iron and other salts on sewage waters has been made use of in their purification and in the collection of the sewage material for fertilizing purposes.

METHODS OF SEPARATING SOIL PARTICLES.

211. Separation of the Soil Into Particles of Standard Size.—

The agronomic value of a soil depends largely on the relative size of the particles composing it. The finer the particles, within a certain limit, in materials of practically the same chemical composition, the better the soil. The size of the particles may be estimated in three ways: (1) by passing through sieves of different degrees of fineness; (2) by allowing them to subside for a given time in water at rest; (3) by separating them in water moving at a given rate of speed. The first method is a crude one and is used to prepare in a rough way, the material for the second and third processes.

212. Separation in a Sieve.—The soil should be dry enough to avoid sticking to the fingers or to prevent agglutination into masses when subjected to pressure. It should not, however, be too dry to prevent the easy separation of any agglutinated particles under the pressure of the thumb or of a rubber pestle.

The sieve should have circular holes punched in a sheet of metal of convenient thickness to give it the requisite degree of strength. Sieves made of wire-gauze are not so desirable but it is difficult to get the finer meshes as circular perforations. Gauze sieves cannot give a uniform product on account of the greater diagonal diameter of the meshes and the ease with which the separating wires can be displaced. It is convenient to have the sieves arranged *en batterie*; say in sets of three. Such a set should have the holes in the three sieves of the following dimensions, *viz.*,

1st sieve	2 millimeters diameter.
2nd "	1 millimeter " "
3rd "	0.5 " "

Coarser single sieves may be used to separate the fragments above two millimeters diameter if such a further classification be desired. Each sieve fits into the next finer one and the separation of a sample into three classes of particles may be effected by a single operation. In most cases, however, it is better to conduct

each operation separately in order to promote the passage of agglutinated particles by gentle pressure with the thumb or with a rubber pestle. In no case should a hard pestle be used and the pressure should never be violent enough to disintegrate mineral particles.

There is much difference of opinion concerning the smallest size of particles which should be obtained by the sieve.

Most analytical processes prescribe particles passing a sieve of one millimeter mesh ($\frac{1}{25}$ inch). There is little doubt, however, of the fact that a finer particle would be better fitted for subsequent analysis by the hydraulic method.

For this purpose a sieve of 0.5 millimeter circular mesh is preferred.

213. Sifting with Water.—In soils where the particles adhere firmly the sifting should be done with the help of water. In such cases the soil is gently rubbed with a soft pestle or the finger in water. It is then transferred to the sieve or battery of sieves which are held in the water, and rubbed through each of the sieves successively until the separation is complete. After the filtrate has stood for a few minutes the supernatant muddy liquor is poured off, the part remaining on the sieve is added to it and the process repeated until only clean particles larger than 0.5 millimeter are left on the sieve. These particles are dried and weighed and entered on the note book as sand. The filtrate should be evaporated to dryness at a gentle temperature and when sufficiently dry be rubbed up into a homogeneous mass by a rubber pestle.

The sieve recommended by the Association of Official Agricultural Chemists for the preparation of fine earth for chemical analysis has circular openings $\frac{1}{25}$ inch (one millimeter in diameter).

Wahnschaffe directs that a sieve of two millimeters mesh be used in preparing the sample for silt analysis and that the residue, after the silt analysis is finished, which has not been carried over by a velocity of twenty-five millimeters per second, be separated in sieves of one millimeter and 0.5 millimeter meshes respectively.

Hilgard objects to leaving this coarse material in the sample during the process of churn elutriation on account of the attrition which it exerts and therefore directs that it be separated by sieve analysis before the elutriation begins.

214. Method of the German Experiment Stations.⁴⁷—In this method an attempt is made to secure even a finer sieve separation than that already mentioned.

Sieves having the following dimensions are employed; sieve No. 1, square meshes 0.09 millimeter in size, diagonal measure 0.11 millimeter; sieve No. 2, square meshes 0.14 to 0.17 millimeter in diameter, diagonal measure 0.22 to 0.24 millimeter; sieve No. 3, square meshes 0.35 to 0.39 millimeter in diameter, diagonal measure 0.45 to 0.50 millimeter; finally a series of sieves one, two and three millimeters circular perforations.

Five hundred grams of the soil (in the Halle Station only 250) are placed in a porcelain dish with about one liter of water and allowed to stand for some time with frequent stirring, on a water bath. After about two hours, when the soil is sufficiently softened so that with the help of a pestle it can be washed through the sieve, the process of sifting is undertaken in the following manner: Sieve No. 3 is placed over a dish containing water, the moistened soil placed therein and the sieve depressed a few centimeters under the water and the soil stirred by means of a pestle until particles no longer pass through. After the operation is ended the residue in the sieve is washed with pure water and dried. The part passing the sieve is thoroughly stirred and then washed with water into sieve No. 2 and treated as before. The product obtained in this way is brought into sieve No. 1 and carefully washed. All the products remaining on each of the sieves are dried at 100° and weighed. The portion passing sieve No. 1 is either dried with its wash water or estimated by loss deducting from the total weight taken, the sum of the other weights obtained. If a more perfect separation of the first sieve residue be desired it can be obtained by passing it through sieves of the last series which may have meshes varying in size, *viz*: one, two, or three millimeters in diameter. Each sieve of the same class should have holes uniformly of the same size.

⁴⁷ Die landwirtschaftlichen Versuchs-Stationen, 1891, 38 : 309.

The sieve products are characterized as follows: The part passing a three millimeter sieve is called fine earth, while the part remaining is called gravel. The fine earth is separated into the following products: The part that passes through the three millimeters opening and is left by the two millimeters opening is called *Steinkies*. The product from the two millimeters opening and the residue from the one millimeter opening is called *Grobkies*. The product from the one millimeter opening and the residue on the sieve No. 3 is called *Feinkies*. The product from the sieve No. 3 and the residue from the sieve No. 2 is called *Grobsand*. The product from sieve No. 2 and the residue from sieve No. 1 is called *Feinsand*. The product from sieve No. 1 is called *Feinsand*. The product from sieve No. 1 is called *Feinsand*. The dust can be further separated into *Staubsand* and *Thon*. For the examination of the clay the Kühn silt cylinder as modified by Wagner, is recommended. The cylinder has a diameter of eight centimeters and a height of thirty centimeters, and is furnished with a movable exit tube reaching to its bottom. Detailed directions for this separation will be given further on. (Paragraph 220).

215. General Classification of the Soil by Sieve Analysis.—The classification recommended by the German chemists is satisfactory but the following one is more simple. All pebbles, pieces of rock, sticks and roots should be picked out of the sample, and the residue of coarse matter be separated by a two millimeters circular mesh sieve, dried at 105° and weighed. The result should be entered as pebbles and coarse sand.

The finer sand may be separated with a sieve of one millimeter circular openings.

The still finer sand is next separated with the sieve of 0.5 millimeter circular openings as indicated above.

The sample may now be classified as follows:

1. Coarse pebbles, sticks, roots, etc., separated by hand.
2. Pebbles and coarse sand not passing a two millimeters sieve.
3. Sand not passing a one millimeter sieve.
4. Fine sand not passing a 0.5 millimeter sieve.
5. Fine earth passing a 0.5 millimeter sieve.

216. Classification of Orth.⁴⁸—As fine earth are reckoned those

⁴⁸ Berichte der deutschen chemischen Gesellschaft, 1882, 15 : 3025.

particles which range from 0.02 to 0.05 millimeter; as fine sand the groups from 0.05 to 0.2 millimeter; as medium sized sand those ranging from 0.2 to 0.5 millimeter and for large grained sand those particles ranging from 0.5 to 2 millimeters in diameter. Particles over two millimeters form the last classification.

217. Nomenclature of Silt Particles.—It is evident from the foregoing discussion that much confusion exists regarding the terms employed to designate the different classes of silt particles obtained by mechanical analysis. Even the classes formed by determining approximately like diameters are differently designated by different investigators. It would be advisable to reach some international agreement respecting the characters of these divisions, leaving to each country the choice of an appropriate name. Such an agreement might be secured through the International Congress of Applied Chemistry.

The chaotic condition of the nomenclature at the present time has been studied by Atterberg.⁴⁰

Especially is it desirable to have some systematic method of describing the fine sand as it merges into clay. Judged by relations to the penetration of rootlets and water the limit of 0.2 millimeter diameter separates porous from water holding particles; while 0.02 millimeter is the limit for coagulability of the fine particles by a solution of sodium chlorid and 0.002 millimeter the limit of marked molecular movement. Particles smaller than 0.02 millimeter cannot be seen by the unarm'd eye. The hair roots of plants cannot penetrate sand finer than 0.02 millimeter diameter.

The decimal system of division has the merit of simplicity and if agreed upon internationally would bring order into what is now great confusion.

The suggested groups of particles with their names in three languages are represented as follows:

Diameter.	Name.		
	Swedish.	German.	English.
From 2.0 to 0.2 mm.	Sand	Sand	Sand
" 0.2 " 0.02 "	Mo	Feinsand	Fine sand
" 0.02 " 0.002 "	Lättler	Lehm	Silt
" 0.002 " finer.	Ler	Thon	Clay

⁴⁰ Chemiker Zeitung, 1905, 29 : 15.

One objection to the plan of grouping by limiting diameters is found in the irregular shape of the particles, which would make them eligible to more than one class, as they might be judged by their long or short diameters. Almost any uniform plan of designation would be better than the present system, in which each investigator uses a separate classification.

SEPARATION OF THE EARTH PARTICLES BY A LIQUID.

218. Methods of Silt Analysis.—The further classification of the particles of a soil passing a fine sieve can best be effected by separation in water. The velocity with which the current moves or with which the particles subside will cause a separation of the particles into various sizes. The slower the velocity the smaller the particles which are separated. There is, however, a large and important constituent of a soil which remains suspended in water, or in a state of seeming solution. This suspended matter would still be carried over by a current of water moving at a rate so slow as to make a subclassification of it impossible. This suspended matter passing off at a given velocity may be classed as clay, and it consists in fact chiefly of the hydrated silicate of alumina, or other particles of equal fineness. The laws which govern its deposit have already been discussed.

The apparatus which have been used for silt analysis may be grouped into four classes.

(1) Apparatus depending on the rate of descent of the particles of a soil through water at rest. The apparatus for decanting from a cylinder or a beaker belong to this class.

(2) Apparatus which determine the rate of flow by passing the liquid through a vessel of conical shape. The system of Nöbel is a good illustration of this kind of apparatus.

(3) Apparatus in which the elutriating vessel is cylindrical and the rate of flow determined by a stop-cock or pressure feed apparatus. The system of Schöne represents this type.

(4) Apparatus in which the above system is combined with a device for mechanically separating the particles and bringing them in a free state into the elutriating current. The system of Hilgard is the type of this kind of apparatus.

In practice the use of cylindrical apparatus with or without me-

chanical stirring and the method by decantation have proved to be the most reliable and satisfactory procedures. Between the beaker and churn methods of separation there is little choice in regard to accuracy. The large number of samples which can be examined simultaneously and the freedom from mechanical difficulties render the method depending on simple subsidence more practical. Which is the superior method respecting accuracy is a question on which the opinions of experienced analysts are divided. The various processes will be described in the order already mentioned.

219. Methods Depending on Subsidence of Soil Particles.—The simplest method of effecting the further separation of the soil particles is without doubt that process which permits them to fall freely in a liquid sensibly at rest. The practical difficulties of this method consist in the trouble of securing a perfect separation of the particles, in preventing flocculation after division and in avoiding currents in the liquid of separation.

For the disintegration of the soil particles in this method boiling and wet pestling are the only means employed. The flocculation of the separated particles may be partially prevented by adding a little ammonia to the water employed. The author has also tried dilute alcohol as the separating liquid but the results of this method are not yet sufficiently definite to find a place in this manual. Evidently the practical impossibility of avoiding convection currents prevents the use of water at a high temperature for this separation although the tendency to flocculation almost disappears as the temperature approaches 100°. The general method of avoiding the errors due to flocculation in the subsidence method consists in repestling the deposited particles and thus subjecting them as often as may be necessary to resedimentation. The principles are well set forth by Osborne,⁵⁰ who states that when a soil is completely suspended in water by vigorous agitation, particles of all the sizes present are to be found throughout the entire mass of liquid. When subsidence takes place, the larger particles will go down more rapidly than the smaller ones, but some of the small

⁵⁰ Connecticut Agricultural Experiment Station, Annual Report, 1886,

particles that are near the bottom will be deposited sooner than some of the larger ones which have a much greater distance to travel. Thus, independently of the fact that the larger particles in their descent are somewhat impeded by the smaller, the smaller being at the same time somewhat hastened by the larger, the sediment that reaches the bottom at any moment is a more or less complex mixture of all the mechanical elements of the soil. The liquid, however, above this sediment at the same moment will have completely deposited all particles exceeding certain dimensions of hydraulic value, determined mainly by the time of subsidence.

If now the aforesaid first sediment be suspended in pure water, and allowed to subside for the same time as before, the larger part of it will be again deposited, but some will remain in suspension, consisting of a considerable part of the finer matter of the first sediment. By pouring off these suspended particles with the water and agitating the sediment again with clear water as before, another portion of fine particles will be suspended and may be decanted from it. On continuing this process of repeated decantations it will soon be found that the soil has been separated into two grades.

It is evident that in this way a separation can be made, but it is perhaps not so clear that such a separation would be sharp enough for the purpose of a mechanical soil analysis. If, for instance, the separation is to be made at 0.05 millimeter diameter, it is evident that by repeated decantations all below 0.01 millimeter can be washed out of that above 0.05 millimeter, but it may not appear so probable that all below 0.045 millimeter can be removed without removing some above 0.055 millimeter.

Such a result may be easily attained, however, if the following principle be adhered to:

Make the duration of the subsidence such that the liquid decanted the first few times shall contain nothing larger than the desired diameter. Then decant into another vessel, timing the subsidence so that the sediment shall contain nothing smaller than the chosen diameter. This can not be done without decanting much that is larger than the chosen diameter, but the greater part

of the particles greater and less than the chosen diameter can be removed and an intermediate product obtained, the diameters of whose particles are not very far from that desired.

If this intermediate portion be again subjected to the same process, two fractions may be separated from it, one containing particles larger than the chosen diameter and another containing particles smaller than this diameter, while a new intermediate product will remain which is less in amount than that resulting from the first operation. By frequent repetitions of this process this intermediate product can be reduced to a very small amount of substance the particles of which have diameters lying close to the chosen limit and may then be divided between the two fractions.

The principles of the separation described by Osborne set forth with sufficient clearness the purposes to be achieved by the analysis, and the method in detail will be found further along.

SEPARATION OF SOIL PARTICLES BY DECANTATION.

220. Kuehn's Silt Cylinder.—A simple form of apparatus for the determination of silt by the sedimentation process is the one described by Kühn.⁵¹

The cylinder should be about 30 centimeters high with a diameter of 8.5 centimeters. At the lower end of the cylinder five centimeters from the bottom it carries a tube 1.5 centimeter in diameter closed by a rubber stopper, the inner end of which must be flush with the inner wall of the cylinder.

In carrying out the process 30 grams of sifted soil (two millimeter mesh sieve) are boiled with water for an hour and after cooling the soil and water are washed into the separating cylinder previously, filled with water to a depth of 28 centimeters. With a smooth wooden stick the contents of the cylinder are stirred vigorously for one minute.

After standing for ten minutes the stop-cock is opened and the water with its suspended matter allowed to flow out, a sample of a given volume being saved.

⁵¹ Steinrede, *Anleitung zur mineralogischen Bodenanalyse*, 1889, 9-13. Die landwirtschaftlichen Versuchs-Stationen, 1893, 42 : 153.

König, *Untersuchung landwirtschaftlich und gewerblich wichtiger Stoffe*, Second Edition, 8.

The cylinder is then again filled with water and the process is continued until the water drawn off is practically clear. The various samples which have been taken are united, thrown on a filter, and the mass remaining on the filter, mixed and subjected to microscopic examination.

The fine particles having been separated in this way in one of the modifications of the method, the next coarser grade of particles is separated by repeating the process and allowing five minutes for subsidence.

By these two operations it is considered that the clay is entirely removed. The residue remaining in the cylinder is dried and weighed. The relative proportions of clay and residue in the sample are thus determined.

The residue is then separated into two portions by sieves of one millimeter and 0.5 millimeter mesh. A third separation with a sieve of 0.25 mm. mesh is also sometimes made.

The soil is thus separated into the following parts:

1. By the first sifting coarse quartz larger than two millimeters diameter.
2. Fine quartz two millimeters, to one millimeter diameter.
3. Coarse sand one millimeter, to 0.5 millimeter diameter.
4. Fine sand finer than 0.5 millimeter diameter.
5. Silt, clay, humus, etc., separated by the water.

221. Knop's Silt Cylinder.—The cylinder recommended by Knop⁵² is essentially that of Kühn being furnished with four lateral tubes instead of one (Fig. 31). The distance between each tube is ten centimeters.

The sample of soil, from 25 to 30 grams, after passing a two millimeter mesh sieve, and long boiling, is washed through a series of sieves of the following diameters of mesh respectively; *viz.*, one millimeter, 0.5 millimeter, 0.25 millimeter, and 0.1 millimeter. The part which passes the finest sieve is placed in a Knop's cylinder, the cylinder filled with water one decimeter above the upper tube and well shaken. The cylinder is allowed to rest for five minutes when the upper cock is opened and the water drawn off. After five minutes more the next tube is opened and so on with equal intervals for the three upper tubes.

⁵² König, *Untersuchung landwirtschaftlich und gewerblich wichtiger Stoffe*, Second Edition, 10.

The operation is repeated with fresh water until the water drawn off is clear. Finally the lowest tube is opened and all the water poured off of the sandy residue. The remaining material is dried and weighed and the weight of silt carried over as determined by difference.

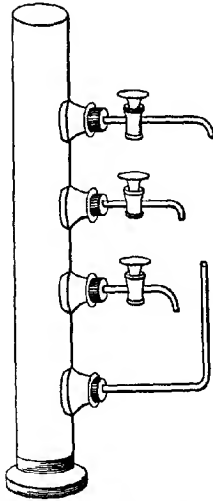


Fig. 31.—Knop's Silt Cylinder.

222. Siphon Silt Cylinder.—Instead of the tubulated cylinder one furnished with a siphon (Fig. 32) can be employed.⁵³

It should be about 40 centimeters high and six centimeters internal diameter. From 20 to 30 grams of the well boiled fine earth is placed in the cylinder and then water added until there is but a small space between it and the stopper when the latter is inserted.

The cylinder is marked at exactly 200 millimeters below the surface of the water with a narrow strip of paper at *a*, stoppered, inverted and well shaken. The cylinder being again placed in normal position the soil particles under the influence of gravity tend

⁵³ Wahnschaffe, *Anleitung zur wissenschaftlichen Bodenuntersuchung*,

to sink with greater or less rapidity according to their size. The siphon *a b c* is filled with water, the cock at *c* closed and the opened end *a* placed in the cylinder A just at the mark 200 millimeters below the surface of the water, and the water thus transferred to B when desired. If the cylinder is allowed to stand for

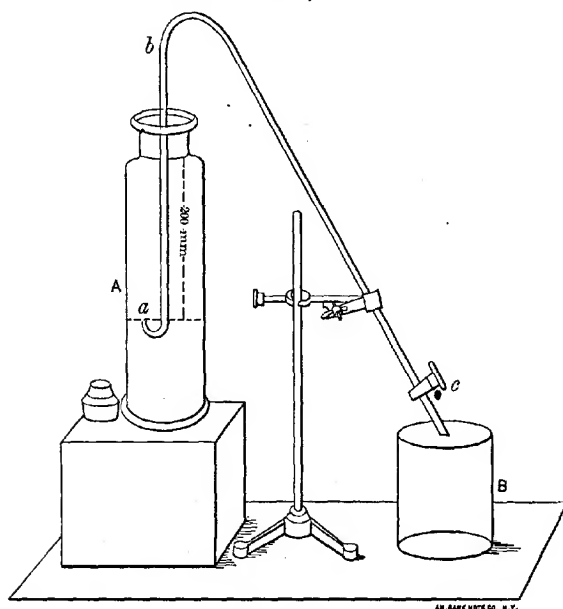


Fig. 32.—Siphon Cylinder for Silt Analysis.

100 seconds the particles of more than two millimeters hydraulic value per second will have fallen below the open end of the siphon. If allowed to stand 1,000 seconds the hydraulic value of the particles will be 0.2 millimeter per second. Whatever the number of seconds may be, the operation is continued until the water removed is practically clear. The open end of the siphon *a* should be bent upwards so that no disturbing current may bring the particles below the line into the liquid discharged into B.

While the results obtained by this method are satisfactory as compared with other similar processes it cannot be highly rec-

ommended because of the time and trouble required to get a complete separation and by reason of the difficulty of collecting the separated silt.

223. Wolff's Method.⁵⁴—As modified by Wolff the Knop process is conducted as follows: From 20 to 30 grams of fine earth are boiled with water and then the entire mixture is passed through sieves with openings of 1, 0.5, 0.25, and 0.1 millimeter in diameter, respectively. The finest part is mixed with water to a height of 18 centimeters in a cylindrical vessel 20 centimeters high and having a capacity of one liter and thoroughly agitated, after which it is left to rest, and finally the turbid liquid is drawn off with a siphon, the bottle refilled with water, agitated, and left to rest, and the process repeated three times or as long as the water carries any suspended matter after a definite time.

Wolff proposes for the first three periods of rest one hour, for the second three, a half an hour, for the third three, a quarter of an hour, and for the fourth three, five minutes.

224. Moore's Modification of Knop's Method.⁵⁵—The sample of soil boiled rapidly with water until the lumps are disintegrated and the clayey portions separated from the sand, is first passed through sieves as described above except the finest. The weight of the particles remaining on the sieves is determined, and that of the portion lost passing through, which is known as fine earth is determined by difference. The last named portion constitutes the material for all subsequent operations of mechanical analysis.

The sediment and water passing through the 0.25 millimeter sieve are placed in a glass cylinder 53 centimeters long and 37 millimeters in internal diameter. The cylinder is closed at the bottom and is provided with a lateral tube inserted six centimeters above the bottom. Three other lateral tubes are inserted at intervals of ten centimeters above the first tube, and a ring is etched into the cylinder ten centimeters above the uppermost tube. The

⁵⁴ Wolff, *Chemische Untersuchung landwirtschaftliche Stoffe*, Berlin, Third Edition, 10.

König, *Untersuchung landwirtschaftlich und gewerblich wichtiger Stoffe*, 9.

⁵⁵ Tenth Census, 8 : 872-3.

lateral tubes are closed with rubber tubes compressed by spring clips. The sediment being placed in the cylinder, water is added to the mark or ring, the cylinder closed with a rubber stopper, and vigorously shaken until the contents are thoroughly mixed. It is then placed upright, the stopper removed, and after standing undisturbed for five minutes the clip on the uppermost tube is opened and the water allowed to flow into a beaker. After five minutes further standing, the second clip is opened and the water drawn off into the same beaker; in the same manner the water is drawn off from the other tubes at intervals of five minutes until the level of the lowest tube is reached. The cylinder is then refilled with water to the mark, thoroughly shaken after inserting the stopper and the water again drawn off at intervals of five minutes, as before; the operation being repeated until the water drawn off is almost free from turbidity. The sediment remaining in the cylinder from this process of washing by subsidence is termed by Knop, fine sand, the material flowing off in suspension in the wash waters, dust, and the process of separation by Knop's original method ends here.

In order to remedy the imperfect separation into definite particles secured by the above method, Moore used the following method:

The fine sand from the first series of subsidences is placed in a separate vessel, the washings are allowed to remain undisturbed for twelve hours, the turbid liquid decanted and the sediment returned to the cylinder. Water is then added to the mark, the whole shaken, and the liquid drawn off at intervals of five minutes, as in the first series. The sediment from this operation is placed in a separate beaker, the washings returned to the cylinder, and again allowed to subside as before; the sediment from this second subsidence is added to that from the preceding operation, and the washings again returned to the cylinder, the operation being repeated as long as any sediment can be obtained from renewed treatment of the washings; the final washings are then placed in a separate vessel for subsequent microscopic measurements.

The collective sediments from the last series of operations are then returned to the cylinder and allowed to subside with fresh

additions of water, as in the case of the first series; the fine sand thus obtained being added to that from the first series, and the washings being collected in a large beaker. The latter is left at rest for twelve hours, and the sediment returned to the cylinder and treated as before until no further separation can be effected. The fine sand resulting from all of these operations is then dried, ignited and weighed; the weight of the portion removed by the washing being determined by difference, as it is, owing to its excessively slow rate of subsidence, found impracticable to collect it for direct weighing. The size of the particles of fine sand is then determined by micrometric measurement. Similar measurements are made on the material obtained by long subsidence from the washings from the foregoing operations. The average diameter of the largest particles should not exceed 0.01 millimeter.

225. Statement of Results.—The results of the analyses on three soils from the localities indicated in the table, and the method of stating them, are given in the following table:

	New Milford Conn., per cent.	Clarks- ville, Tenn., per cent.	Gran- ville, N. C., per cent.
Particles larger in diameter than 3.0 millimeters.....	8.55	0.32	0.23
Particles of diameter from 3.0 millimeters to 1.0 millimeter.....	4.96	0.45	15.04
Particles of diameter from 1.0 millimeter to 0.5 millimeter.....	4.43	0.96	33.43
Particles of diameter from 0.5 millimeter to 0.25 millimeter.....	11.86	1.25	18.82
Particles of diameter from 0.25 millimeter to 0.01 millimeter.....	60.54	61.58	23.59
Particles smaller in diameter than 0.01 millimeter.....	9.66	35.44	8.89
Total	100.00	100.00	100.00

226. Claussen's Apparatus.—The apparatus is constructed on the principle of that of Bennigsen, given further on, but is capable of giving more exact results.³⁰

It is composed of two pieces, a pear-shaped bulb and a long neck. The long neck of the bulb as described in Bennigsen's

³⁰ Wahnschaffe, *Anleitung zur wissenschaftlichen Bodenuntersuchung*, 28. *Illustrierte landwirtschaftliche Zeitung*, 1889 : 29.

method has a diameter of 2 cm. for 75 cm., and is then drawn out into a smaller tube 25 cm. long and 11 mm. diameter. The bulb and long stem are joined together by a heavy rubber band. The sample of air-dry earth which has passed a 2 mm. mesh sieve, is placed in the pear-shaped bulb of the apparatus and boiled for half an hour with water. About 30 grams of the fine earth are used and during the boiling the flask is frequently shaken. After cooling the bulb is filled almost full of water and the long stem closed at the lower end with a rubber stopper and filled with water, is fixed in place by the rubber band. After repeated shakings the whole apparatus is quickly inverted and the solid contents of the bulb begin to descend through the long neck. The sand and clay are fairly well separated during the descent and the relative quantities of fine and coarse particles are measured by the divisions on the lower constructed portions of the tube. The tube may now be separated from the bulb, its upper end closed by the finger, the stopper removed from the end containing the separated particles, and these allowed to run out in portions as nearly the same size as possible as in the manipulation of a pipette. The several portions are then dried and weighed. As in the preceding case it is evident that this process can give at best only an approximate separation.

227. Method of Gasparin.—The method of Gasparin only gives a very primitive separation of the various components of the earth according to their fineness.³⁷ It is conducted as follows:

Ten grams of sifted earth are put into a beaker, water is added and strongly agitated; after five minutes the water is decanted into another vessel, the first vessel is filled anew with water, agitated, decanted, and this process is repeated until the liquid remains perfectly clear. Only two portions are weighed, *i. e.*, the pebbles which remain in the sieve and the coarse sand which remains in the beaker; while the argillaceous portion drawn off with the water is determined by the difference.

228. The Italian Method.—The following modification of Gasparin's process is practiced by the Italian chemists:³⁸

Twenty grains of earth are passed through a sieve having open-

³⁷ *Encyclopédie chimique*, 4 : 138.

³⁸ *Stazioni sperimentali agrarie Italiane*, 1889, 17 : 672.

ings of one millimeter in diameter, then the sifted part is mixed with 100 cubic centimeters of water in a 200 cubic centimeter beaker and left to rest for some hours, strongly agitated, and after ten seconds the turbid liquid is poured into another vessel of half a liter capacity. This manipulation is repeated until the liquid is clear.

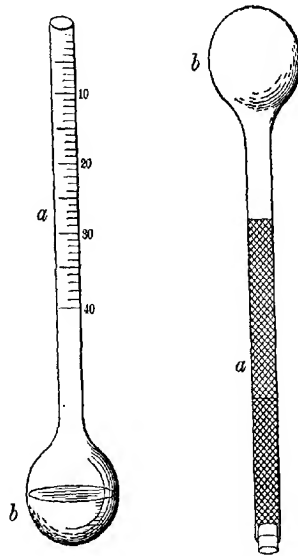


Fig. 33.—Bannigsen's Silt Flasks.

The decanted liquid is thoroughly agitated, then left to stand until the movement shall be completely arrested, after which the supernatant liquid is poured into another vessel holding two liters. To the residuum is added more water; it is agitated, decanted, and this process is repeated until the water is no longer turbid.

229. Method of Bannigsen.—The silt flasks recommended by Bannigsen⁵⁹ are shown in Fig. 33.

⁵⁹ Wahnschaffe, *Anleitung zur wissenschaftlichen Bodenuntersuchung*, Second Edition, 28.

The glass flask *b* carries a long cylindrical neck *a* the upper part of which is graduated in cubic centimeters. Ten grams of the fine soil are shaken with water in the flask, the neck of which is closed with a rubber stopper. The flask is then inverted bringing the soil and the water into the neck. The flask is hung up and sedimentation is assisted by imparting a pendulous motion to the neck for ten minutes. This manipulation results in the sedimentary action due to gravity being aided by a slight centrifugal force. After an hour the soil particles have separated into a coarse layer below and a fine layer above, as indicated by the different shading on the neck of the inverted flask. The relative volumes of the two layers are then read off in cubic centimeters. While this method may be useful in helping to form a speedy judgment concerning the character of a soil it can lay no claim to being an accurate method of silt separation.

230. Method of Osborne.—In the foregoing paragraphs the methods of silt separation by subsidence as practiced in different countries have been outlined. The good points of the various methods are combined in the process as carried out by Osborne. The general principles on which this process rests have already been outlined. The details of this method will be given with sufficient minuteness to make its practice possible by all analysts.

Selecting the Sample.—Several pounds of air-dried, fine earth are secured by passing the soil through a sieve, the holes of which are three millimeters in diameter.

Sifting.—Thirty grams of the above fine earth are stirred with from 300 to 400 cubic centimeters of water and then thrown successively upon sieves with circular holes of $\frac{1}{8}$, 0.5, and 0.25 millimeter diameter respectively. By means of successive additions of water and the use of a camel's hair brush, all the fine material is made to pass through the sieves and these at the last are agitated under water in a shallow dish in such a way that the soil is immersed. The finest sieve should be well wet with water on its lower surface just before using. The finest particles which render the water turbid are easily washed through. The turbid water is kept separated from the clear water which comes off with the last portions that pass the sieves. The turbid water usually does not amount to more than one liter.

Elutriation.—The elutriation should be carried on so as to secure three grades of silt; the diameters of the particles ranging in the first grades from 0.25 to 0.05 millimeter, in the second grade from 0.05 to 0.01 millimeter, and in the third grade from 0.01 millimeter to the impalpable powder. The term sand is applied to the first grade, silt to the second, and dust or dust and clay to the third. After the turbid liquid from the sifting has stood a short time it is decanted from the sediment and after standing until a slight deposit is formed, is again decanted and the sediment examined with a microscope. If sand be present, the subsidence of the turbid liquid is continued until no more sand is deposited. As the sand subsides rapidly there is no difficulty in altogether freeing the liquid first decanted from this grade of particles. The sediment thus obtained contains all the sand, a part of the dust and much silt. As only dust and the finest silt render the water turbid the sediment is stirred a few times with a fresh quantity of water and decanted after standing long enough to let all the sand settle. When the water decanted is free from turbidity, the last portions of the soil passing through the sieve with clear water are added to the sediment and the decantations continued so as to remove most of the silt. When no more silt can be easily removed from the sediment without decanting sand, the decantations are made into a different vessel and the subsidences so timed as to remove as much of the silt as possible. By using a little care, at least three-quarters of the sand are thus obtained free from silt. The rest of the sand is mixed with the greater part of the silt which has been decanted into the second vessel. The size of the smallest particles in this vessel is determined with the microscope, to make sure that its contents are free from dust as they usually will be if, after settling for a few moments, they leave the water free from turbidity.

The soil is thus separated into three portions, one containing sand, one sand and silt, and the other silt, dust, and clay. The sand and silt are separated from each other by repeating the subsidences and decantations in the manner just described.

In this way there is removed from the sediment, on the one hand, a portion of silt free from sand and dust, and on the other hand a portion of sand free from silt. Thus is obtained a second

intermediate portion consisting of sand and silt, but less in amount than the first and containing particles of diameters much more nearly approaching 0.05 millimeter. By repeating this process a few times, this intermediate portion will be reduced to particles whose diameters are very near 0.05 millimeter and which may be divided between sand and silt, according to judgment. The amount of this is usually very small. As soon as portions are separated, which the microscope shows to be pure sand or pure silt, they are added to the chief portions of these grades already obtained.

The same process is applied to the separation of silt from dust. When all the silt has been removed from the dust and clay, the turbid water containing the dust and clay is set aside and allowed to settle in a cylindrical vessel for twenty-four hours. The vessel is filled to a height of 200 millimeters. According to Hilgard, the separation of the dust from clay during a subsidence of twenty-four hours, will give results of sufficient accuracy, although the clay then remaining suspended will not be entirely free from measurable fine particles up to 0.001 or 0.002 millimeter diameter.

Small beakers and small quantities of distilled water are used at first for the decantations, as thus the duration of subsidence is less and more decantations can be made in a given time than when larger quantities of water are employed. Beakers of about 100 cubic centimeters capacity are convenient for the coarser grades, but it is necessary to use larger vessels for the fine sediments from which turbid water accumulates that cannot be thrown away, as may be done with the clear water, from which the coarse sediments settle out completely in a short time.

It is best to keep the amount of water as small as possible in working out the dust since loss is incurred in using too large quantities.

It is also necessary in most cases to subject the various fractions obtained during elutriation, to careful kneading with a soft rubber pestle so that the fine lumps of clay may be broken up and caused to remain suspended in the water. This treatment with the pestle should be done in such a way as to avoid as far as possible all grinding of the particles, the object being merely to pul-

verize the minute aggregations of clay and extremely fine particles which always form on drying a sample of soil after removing it from the field.

Measurement of the Particles.—To determine the size of particles in suspension, a small glass tube is applied to the surface of the liquid in such a way as to take up a single drop which is transferred to a glass slide. This drop will contain the smallest particles in the liquid.

To obtain a sample of the coarsest particles the liquid is allowed to stand long enough to form a very slight sediment and a portion of this sediment is collected with a glass tube.

To determine the diameter of the particles in a sediment it is stirred vigorously with a little water and the pipette at once applied to the surface of the water. On decanting the greater part of the sediment, the large particles remain at the bottom of the beaker and may be easily examined.

Time.—The time required to make the separations, above described, is about two hours for each, so that an analysis including the siftings, is made in five or six hours, exclusive of the time necessary for collecting the dust and separating the clay, for which a subsidence of 24 hours is allowed.

Weighing the Sediments.—The sediments are prepared for weighing by allowing them to subside completely, decanting the clear water as far as possible, rinsing them into a weighed platinum dish and igniting. The dish is cooled in a desiccator, and the ignited sediments are generally very hygroscopic.

Effect of Boiling.—The analyses show a very decided increase in the particles smaller than 0.01 millimeter diameter at the expense of coarser particles as the result of boiling. The surfaces of the coarser particles are seen to be polished and of a lighter color than those not boiled. The surfaces of the unboiled particles are coated with a film of fine material probably cemented to them by clay. When these coarse particles which have not been boiled, are violently stirred with water for a short time, no fine particles are detached from them; and a careful examination under the microscope fails to reveal in any of the sediments more than an occasional grain exceeding the 0.05 millimeter limit by so much as 0.01 millimeter, or the 0.01 limit by as much as 0.005.

millimeter. It would, therefore, appear that these small particles thus set free by long boiling are really a part of the larger ones and should be treated as such in a mechanical analysis of these soils.

231. The French Method.—The consulting committee of the, agricultural experiment stations and agricultural laboratories preface the description of the methods of mechanical analysis with the assumption that the soil is essentially formed of four elements, *viz.*, sand, clay, lime and humus. They reject the methods originally proposed by Gasparin and Masure and propose in their place the process described below.

The Schloesing method⁶⁰ as practiced by the French agricultural chemists⁶¹ differs essentially from those already described in attempting to first free the silt from carbonates and organic matter. It is conducted as follows:

One kilogram of the soil previously dried in the air, is passed through a sieve of five millimeter mesh. The agglomerated particles of earth are broken up by the hand. The pebbles and parts not passing through the sieve are weighed. The pebbles are then treated with hydrochloric acid until all effervescence is over. The insoluble part is dried and again weighed. The difference in weight gives the quantity of calcium carbonate contained on the external surface of the pebbles. The earth which passes the sieve of five millimeters mesh is next passed through a sieve having ten meshes to the centimeter. The masses on the sieve are broken up with the hand or with a soft pestle, in such a manner as to separate the fine agglomerated particles. The material which remains upon the sieve after being dried at 100°, is weighed. This gives the coarse sand. This is treated with hydrochloric acid as were the pebbles before, washed and the residue dried and weighed. The difference in weight gives the quantity of calcium carbonate adhering to the surface of the coarse sand.

The mechanical analysis is continued with the matter which has passed the sieve with ten meshes to the centimeter and which consists of the soil, properly so-called. Ten grams of this are dried at 100° until no further loss takes place and the moisture thus de-

⁶⁰ Encyclopédie chimique, 4 : 135 et seq.

⁶¹ Annales de la Science agronomique 1891, 1, 2 fascicule : 250 et seq.

terminated. Another 10 grams are placed in a capsule with a flat bottom, and from nine to ten centimeters in diameter. The earth is moistened with a small quantity of water in such a way as to make a paste. This paste is rubbed up with the finger in from 15 to 20 cubic centimeters of water. Ten seconds after the stirring is completed the supernatant liquid is poured into a precipitating jar of about 250 cubic centimeters capacity, taking great care not to allow any particles to pass over which have been deposited during that time. This operation is repeated in the same way waiting about ten seconds each time before decanting, until the decanting liquor is almost perfectly clear. In this way the particles of different degrees of fineness are separated. The decanted portions contain the fine sand and clay. The remaining portion contains the coarse sand. This last part is dried, being kept at 100° until it has a constant weight. It is afterwards treated with dilute nitric acid to dissolve the calcium carbonate. When the carbonate is abundant, it is sufficient to determine it by difference which is done by washing the material, drying and weighing. But when the proportion of carbonate is very small and in consequence when its exact determination acquires a greater importance, it is better to determine the lime directly. For this purpose the part soluble in dilute nitric acid is collected, treated with ammonia and acetic acid and precipitated with ammonium oxalate. Details of this operation will be given in another part of this manual.

In regard to the matter which is insoluble in nitric acid, it is composed chiefly of silica or silicates, and sometimes also of vegetable *débris*. The vegetable matter is determined by the incineration of the material which has been previously dried. The loss of weight gives the proportion of vegetable or organic *débris* contained in the soil and of combined water.

The portion which has been decanted, the volume of which should not exceed 500 cubic centimeters, is treated with nitric acid until effervescence ceases. It is then left to digest for some time, in order to permit the whole of the carbonate to dissolve. It is next thrown upon a smooth filter about one decimeter in diameter. After filtration it is washed to secure the complete elimination of

the soluble lime salts. The lime is determined in the filtered liquid.

The insoluble portion contains the fine sand, the clay and humus bodies. In order to separate the three elements the precipitate which was received upon the filter, is detached with water, the filter is broken and all its contents washed through. The volume of wash water is made up to 200 cubic centimeters; two or three cubic centimeters of ammonia are added and the whole left to digest for two or three hours. The volume of the liquid is then made up to one liter with distilled water, vigorously shaking in such a way as to put all the matter in suspension. It is then left to settle for 24 hours. At the end of this time the supernatant liquid is decanted by the aid of a siphon. To the residue are added two cubic centimeters of ammonia and one liter of water. The matter is again brought into suspension and allowed to settle for 24 hours. The supernatant liquid is again decanted with a siphon, and added to the liquid previously removed. For ordinary soils two decantations are generally sufficient but when the soils contain a large quantity of clay it is convenient to decant three or four times. By an examination of the supernatant liquid it is easy to tell if the washings have been sufficiently prolonged. The decanted liquors contain the organic matter and that which it is convenient to call clay, which is constituted of very fine particles of sand and colloidal clay which play, in arable soil, a rôle somewhat like that of cement.

These matters are estimated in the following manner: The liquor is first treated with nitric acid and the clay and the humic matters are precipitated together. They are collected upon a smooth filter one decimeter in diameter and washed with water. By means of a washing-bottle all the solid matters which have stuck to the sides of the filter are finally collected in the bottom of it. Since the last washings pass the filter very slowly, they can be removed after the complete deposition of the matter they contain, by means of a pipette. When all the liquid is removed the filter is placed upon blotting paper, great care being taken to avoid desiccation, having in view only the elimination of the excess of humidity. The folds in the filter are then carefully smoothed out with the finger. The matter which has collected

upon the filter is then removed completely with a washing bottle, placed in a dish and dried at 100° and weighed. After weighing, the mass is incinerated in a muffle in order to destroy the humic bodies. The difference in weight before and after incineration, gives the total weight of the humic bodies and since the diminution in weight comprises not only the weight of the humic bodies, but also the weight of the combined water which is lost during the process of incineration, there should be subtracted from the total loss of weight ten per cent of the weight of the residual mineral matter, which represents the water of composition of the hydrated silicate. In this way the two chief cementing bodies of the soil are determined.

232. Statement of the Analysis.—Schloesing in his original paper⁶² recommends that the results of analysis be computed to 1,000 grams of soil. The data of the analysis and the method of arrangement are illustrated by the following example.

The physical examination of the earth having been completed as above, the results can be tabulated on a quantity of soil equivalent to 1,000 grams of dry earth, as follows: Digest in water, thoroughly work by hand, sift, and pass through sieve one millimeter mesh by aid of water.

	Grams.
Dry residue, 55 grams, contains {	
Pebbles	21
Gravel	33
Organic débris	1
Sifted earth by difference, $1000 - 55 =$	945
	1000

The water content of the homogeneous paste is 27 per cent. Then 945 grams of the dry sifted earth correspond to 1294.5 of paste.

The analysis, therefore, should be carried on upon this weight, or some aliquot part say 0.01 thereof; viz., 12.945 grams.

	Grams.
12.945 grams of	
be paste after suc-	
cessive kneadings	
and decantations	
furnish dry:	
1st.—Coarse sand {	
dry giving by treat-	
ment with acid and	
ignition.	
2nd.—Fine elements decanted with the water, their	
weight calculated by difference, $9.45 - 4.32 =$	5.13
grams.	
	Noncalcareous sand 3.05
	Calcareous sand.... 1.19
	Organic débris..... 0.08

⁶² Encyclopédie chimique, 4 : 155 et seq.

Treatment of the Fine Elements.—Treat with nitric acid until a complete decomposition of the calcareous matter is secured, filter, wash, the residual matter collected upon a filter, and collect the filtrate in a two-liter flask, add a little ammonia, allow to digest, fill the flask with distilled water, leave for 24 hours at repose, and decant:

	Grams.
The decantation furnishes {	
1st.—A deposit of fine noncalcareous sand weighing dry	3.14
2nd.—Clayey liquid giving after coagulation by acid filtration, and drying 0.85 grams of clay.	
Then: Total fine elements.....	5.13
Pine elements determined directly. {	
Fine noncalcareous sand ..	3.14
Clay	0.85
	3.99
Fine noncalcareous sand by difference	1.14

Calculating these results to the original quantity of 1,000 grams the following data are obtained:

RESUME.

One thousand grams of dry earth contain:

Pebbles	21 grams.
Gravel	33 "
Organic débris	1 gram.
Fine earth.....	945 grams.
Total	1000 "

		Grams.		Grams.
945 grams of fine earth contain:	{ Coarse sand.....	432	Noncalcareous sand.....	305
			Calcareous sand	119
			Volatile matter	8
	{ Fine elements...	513	Fine, noncalcareous sand.....	314
			Clay	85
			Fine calcareous sand.....	114
	Total			945

As clay are counted all the elements which have remained in suspension in the water after a period of repose of 24 hours. In fact, these elements comprise a notable proportion of very fine sand which is not deposited during that time. In order that the liquid should become entirely freed from this sand it would be necessary to wait several weeks and even several months. Such a prolongation of the analysis is evidently inad-

missible. The period of 24 hours of repose therefore has been adopted. This is merely conventional, in the same way that the period of ten seconds adopted for the precipitation of the gravel is conventional. But this convention is justified by the fact that the substance which is called clay presents, when it has a proper degree of humidity and cohesion, a plasticity entirely analogous to that of natural clay. Moreover, as has already been said, that which is chiefly important in these analyses is the employment of processes always comparable among themselves in their results and generally followed.

233. The Belgian Method.—The method of estimating the percentage of sand and clay practiced at the Gembloux Station⁸³ is essentially that recommended by Schloesing with a few minor modifications.

With the ball of the thumb or with the finger, 100 grams of fine earth are rubbed with water in a porcelain capsule or mortar with a capacity of about 250 cubic centimeters. The suspended particles are poured off with the wash water and the process repeated five or six times, using in all about 200 cubic centimeters of water.

The water containing the sediment is rendered slightly acid (hydrochloric) adding the acid in minute quantities with frequent stirring for about an hour in order to dissolve all the carbonate and to separate the organic acids from the bases with which they are combined.

The liquid is allowed to remain at rest for five or six hours and a part of the liquor decanted to remove any supernatant particles of organic matter which may have passed the sieve in the original preparations of the sample. Filter through a smooth filter about 12 centimeters in diameter, wash until the chlorin has disappeared, and throw the filtrate away.

Break the filter paper over the vessel in which the soil was treated with hydrochloric acid and wash all the contents of the filter into this vessel with as little water as possible (about 100 cubic centimeters at most), add five cubic centimeters of strong ammonia water, allow to stand for three hours, shaking from

⁸³ Petermann, *L'analyse du sol*, 15.

time to time and with distilled water make the volume up to 250 cubic centimeters. Stir vigorously with a glass rod, take this out and wash any adhering particles back, leave at rest for 24 hours, and siphon the turbid liquid into a two-liter vessel. Make the volume up again to 250 cubic centimeters and treat as above described and repeat the operation until the water becomes clear. Usually eight or ten washings are necessary. Wash the residual sand into a weighed dish, evaporate to dryness, ignite and weigh. The weight obtained divided by the weight of the original sample gives the per cent of sand. The sand is separated by sieves of varying fineness into coarse, fine, and pulverulent sand.

Add to the ammoniacal liquor collected in the two-liter flask some powdered potassium chlorid (five grams per liter) to hasten the coagulation and rapid deposit of the clay.

After 24 hours siphon the clear liquor, collect the deposited clay in a smaller vessel, allow to remain at rest and decant as much of the clear liquor as possible. Pass through a plain tared filter about nine centimeters in diameter, wash and dry at 150° and weigh the clay.

234. The Italian Method.—Schloesing's method as carried out by the Italian chemists⁶⁴ is as follows:

A kilogram of air-dried earth is separated into two portions by a sieve of five millimeter mesh.

With another sieve having spaces of one millimeter, the coarse sand is separated. The pebbles and sand are dried, weighed, treated with hydrochloric acid and again weighed in order to find the quantity of calcareous matter contained in them. In ten grams of the fine earth passing the second sieve the humidity is determined by drying at 100°.

Ten grams are thoroughly mixed in a capsule with from 15 to 20 cubic centimeters of water and after eight to ten seconds the supernatant liquid is poured into a beaker having a capacity of 250 cubic centimeters. The same operation is repeated until there are contained in the beaker the fine sand and the clay, while the coarser sand remains in the capsule.

This last is then dried and weighed and the quantity of calcium

⁶⁴ *Le stazioni sperimentali agrarie Italiane*, 1889, 17 : 672 et seq.

carbonate determined by treating it with diluted nitric acid. By means of calcination the organic matter is determined. The liquid decanted in the beaker, the volume of which must not surpass 200 or 250 cubic centimeters, is treated with nitric acid, filtered after some time, washed and the calcium is directly determined by precipitating the solution with ammonium oxalate as will be described further along.

The part in the filter which contains the fine sand, the clay, and the humus material is mixed with water to a volume of about 200 cubic centimeters; there are then added two to three cubic centimeters of ammonia and after two or three hours it is diluted to a liter and strongly agitated.

After 24 hours of rest it is decanted and the residuum is treated a second time with diluted ammonia, decanting after 24 hours. Ordinarily these two treatments suffice, if, however, the earth is very argillaceous, this operation should be repeated three and even four times.

The clay which is found in the liquid suspended in colloidal form coagulates and is precipitated by adding from 30 to 40 cubic centimeters of a saturated solution of potassium chlorid, while the humus substance, under the influence of the ammonia remains dissolved.

Sestini found that the method of Schloesing was the only one which indicated exactly the quantity of clay in the soil. He modified this method by reducing the time of rest from 24 hours, as proposed by Schloesing, to only 12 hours, a reduction which in his opinion does not in the least impair the exactness of the method.

Sestini also proposes 12 treatments instead of six.

235. Method of Williams-Fadejeff.—A very full discussion of the principles of silt analyses and some of the more common methods employed is found in a paper by Williams⁶⁵

In the process finally recommended, *viz.*, the Williams-Fadejeff method, the larger particles are separated after proper pestling and boiling by sieves and the smaller particles passing 0.25 mm. mesh are subjected to separation in water.

⁶⁵ *Forschungen auf dem Gebiete der Agrikultur-Physik*, 1895, 18 : 225 et seq.

The treatment of this portion is as follows:

The principle on which this method rests is much like that of the beaker process. The apparatus used in this process is composed of glass cylinders of the following dimensions:

<i>a</i>	12	cm. high and	6	cm. in diameter.
<i>b</i>	12	" " "	20	" " "
<i>c</i>	12	" " "	22	" " "
Two <i>d</i>	35	" " "	17	" " "

The soil emulsion previously boiled and having the coarser particles removed by a sieve is placed in a porcelain dish and added little by little to the vessel *a* to a depth of 10 cm., allowed to stand for 5 minutes and the liquid portion poured into *b* and the process continued until the whole sample is in *a* and *b*. The part remaining in *a* is stirred with distilled water, allowed to stand 5 minutes, and poured into *b*, and this is continued until there is no longer any marked turbidity produced.

The cylinder *b*, if not already full, is filled to a depth of 10 cm. with water, its contents well stirred and allowed to stand 24 hours. With a suitable siphon the part in suspension is transferred to one of the cylinders *d*. Water is added to the residue in *b* and this process repeated until the water after 24 hours is no longer turbid.

To each of the *d* cylinders is added 10 cc. of a concentrated calcium chlorid solution and the contents stirred until the suspended silt is coagulated. When the supernatant liquid is clear it is drawn off by a siphon. The precipitate in the two *d* cylinders is removed for later investigation. The soil precipitate remaining in *b* is boiled for 42 hours, adding water from time to time in a porcelain dish covered with a watch glass, passed through a sieve of 0.25 mm. mesh again into *b* and water added to the depth of 10 cm. The lost portion of the water used for filling up to that depth should be got from renewed washings of the residue in cylinder *a*.

The contents of *b* are well shaken and allowed to rest for six hours and the liquid part siphoned into *c*. The muddy water in *c* is allowed to stand for 24 hours and then siphoned into *d*, and this process is continued until the water is clear. The wash waters added to that previously collected from the subsidence in

d are again treated with the concentrated chlorid of calcium solution, the solution after the subsidence of the silt removed by a siphon and the collected silt dried and weighed. This process is justly regarded as very tedious and appears to have no superiority in any respect to the beaker method. For further details of the process which are given at great length the reader is referred to the original article.

236. Comparison of the Above Methods with Others.—Puchner has compared the results obtained by the above method with those given by the Hilgard, Kühn and Mayer's processes.⁶⁶

The data secured are found in the following table:

Kind of soil.	Clay Hilgard. Per cent.	Schlamm Fadejeff- Williams. Per cent.	After Kühn.	After Mayer.
Porcelain earth	43.28	44.44	100.00	100.00
Sandy soil	10.40	19.90	59.46	60.40
Quarz sand	0.50	1.58	9.00	10.90

Puchner asserts that the data obtained by the Fadejeff-Williams method are less likely to be burdened with error than those secured by the Hilgard process. His reasoning, however, based as it is on such a small number of analyses, is far from convincing. The serious manipulatory objections to the use of the Fadejeff-Williams method are sufficient to render the process only of scientific and not practical interest.

237. Apparatus of Gawabowski.—This apparatus and method are based largely on the principle of the process of Nöbel and are intended more for commercial and farmers' use than for scientific purposes.⁶⁷ The author also recommends its use in the separation of Thomas slag. Its cheapness and ease of use recommended it for the purpose above named. The author compared the results obtained with those given by Nöbel's apparatus and found them quite concordant.

238. Fine Sands in a Soil Rich in Humus.—Schloesing has prepared a method for automatically separating the fine particles just above the colloidal particles of a soil, rich in humus (*terre*

⁶⁶ Die landwirtschaftlichen Versuchs-Stationen, 1901-02, 56 : 145.

⁶⁷ Zeitschrift für analytische Chemie, 1901, 40 : 776.

vegetale) by the rate at which they pass through the center of a mass of water and by the weight of particles passing in a given time.⁶⁸

A cylindrical vessel 33 centimeters long having a bottle shape neck at each end is so arranged that by an ingenious device in connection with a mariotte bottle a certain quantity of water carrying the fine particles is delivered at the lower orifice and collected in a series of capsules moved by clock-work. The mariotte bottle and the clock-work permit the analyst to leave the apparatus to automatic working, after it is once started. The operator who spends one hour and 20 minutes in starting the process in the afternoon will find the analysis complete the morning of the morrow. For the details of construction of the apparatus and of the manipulation the reader is referred to the original paper.

239. Method of Nefedof.—This method is based upon the theoretical assumption that particles of a given density and size, evenly distributed through a liquid (water), obey the same laws of descent as if falling in the same medium in independent particles. A necessary condition for the conduct of the method is that the mixture do not exceed a certain density, otherwise a flocculation of the particles will take place, and the independence of the individual particles be lost. To avoid this the author recommends a trituration of the moist soil with a soft pestle until all flocculations are destroyed and the subsequent suspension of the mass in water for a given time. The difficulties of securing in practice the theoretical conditions prescribed are too great to justify a hope of great improvement as a result of the method.⁶⁹

SEPARATION OF THE SOIL PARTICLES BY A LIQUID IN MOTION.

240. General Principles.—The laws, already discussed, applying to the subsidence of a solid particle in a liquid, are equally applicable to the separation of the particle by imparting an upward motion to the liquid at a given rate. If a solid particle subside in a given liquid at the rate of one millimeter per second it follows that this particle will remain at rest if the liquid be set in motion

Comptes rendus, 1903, 137 : 369.

Journal (Russian) für experimentelle Landwirtschaft, 1902, 447.

upward with a like velocity. If the velocity be greater the particle will be carried upward and eventually out of the containing vessel. Such a particle is said to have a hydraulic value of one millimeter per second. If there be a perfect separation of a soil into its constituent particles and no subsequent flocculation, all the particles of one millimeter hydraulic value and less will be separated by a current of the velocity mentioned.

The general principles on which the separation rests, therefore, are the securing of the proper granulation of the sample and the maintenance of a fixed velocity of the current until the separation is finished. The separation must be commenced with a period of subsidence so as to remove first of all the suspended clay or impalpable particles. The velocity can then be increased in a certain fixed ratio to secure a separation into particles of any required hydraulic value.

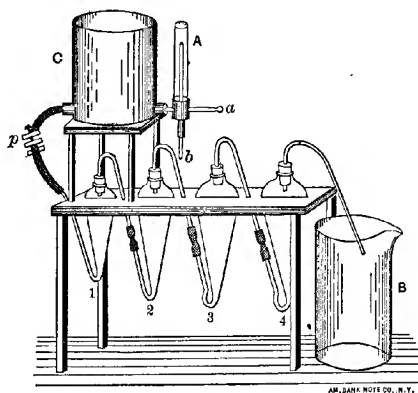


Fig. 34.—Nöbel's Elutriator.

241. Nöbel's Apparatus.—One of the earliest methods of separating the soil particles by a moving liquid is that of Nöbel.⁷⁰ The apparatus is shown in Fig. 34. The four separating vessels 1, 2, 3, 4 are of glass, pear-shaped, and have a relative capacity of 1³, 2³, 3³, 4³, or 1:8:27:64. No. 4 has an outlet tube leading to the beaker B, of such a capacity as to allow the passage of just nine

⁷⁰ *Zeitschrift für analytische Chemie*, 1864, 3 : 89.

liters of water in 40 minutes, constant pressure being maintained by means of a Mariotte's bottle or of the constant level apparatus A, *a*, *b*, which is connected with the main water supply through the tube *a* by means of a rubber hose. The reservoir C should hold about ten liters. The sample of soil to be separated should be previously boiled and passed through a sieve having circular openings one millimeter in diameter. The flask in which the sample is boiled is allowed to stand for some time when the muddy supernatant liquid is poured into elutriator No. 2 and the remaining sediment washed into No. 1. No. 1 is filled with water by connecting it with the water supply and opening the pinch-cock *p*. The water is carefully admitted until the air is all driven out and Nos. 1 and 2 connected. The cock *p* is then opened and the vessels all filled, and the water allowed to run into B for forty minutes, the level being maintained uniformly at A.

Of the water used, 4 liters are found in the elutriating vessels and 5 liters in the receiving vessel No. 5. The apparatus is left standing for an hour until the liquid in the elutriators is clear and the portions in each vessel are received on weighed filters dried at 125°, and the weight of each portion determined.

It is recommended that the loss on ignition of each part be also determined. The separated particles thus secured are classified as follows:

No. 1. Débris and gravel. No. 2. Coarse sand. No. 3. Fine sand. No. 4. Clayey sand. No. 5. Finest parts or clay.

Although the method of Nöbel has been much used, the results which it gives are entirely misleading. The convection currents produced in the conical vessels by the passing water and the flocculation of the soil particles prevent any sharp separation into classes of distinct hydraulic value. The process may be useful for a qualitative test, but its chief claim to a place in this manual is in its historic interest arising from its use in the first attempts at silt analysis.

242. Method of Dietrich.⁷¹—The difficulties attending the silt separation by the Nöbel method, led Dietrich to construct an apparatus in which the sides of the elutriating vessels are parallel,

⁷¹ *Zeitschrift für analytische Chemie*, 1866, 5 : 295.

but these vessels, with the exception of the first, are not set in an upright position.

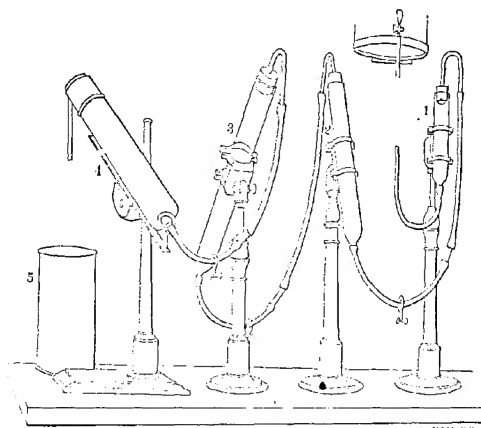


Fig. 35.—Dietrich's Elutriator.

The apparatus (Fig. 35) consists of a series of cylindrical vessels connected by rubber tubing.

The elutriators are of the following dimensions:

No. 1. Seventeen centimeters long, 2.8 centimeters in diameter, position upright.

No. 2. Thirty-four centimeters long, four centimeters in diameter, inclined $67^{\circ}.5$.

No. 3. Fifty-one centimeters long, 5.2 centimeters in diameter, inclined 45° .

No. 4. Sixty-eight centimeters long, 6.4 centimeters in diameter, inclined $22^{\circ}.5$.

The rubber tubes passing from one vessel to the other are furnished with pinch-cocks so that each one of the elutriating vessels can be shut off from the others and independently removed from the circuit.

The stream of water is made to pass through the apparatus under a constant pressure of one meter.

Only the fine earth, boiled with water or hydrochloric acid, is to be placed in the apparatus. The part coming through a sieve with a mesh 0.67 millimeter is to be used and placed in No. 1. About

30 grams of soil are employed for each elutriation. Before adding the soil, the air is completely removed from all parts of the apparatus by connecting it with the water supply and allowing it to be filled with water.

The rate of flow is controlled by the orifice of the last effluent tube and the analyst is directed to continue the operation until the effluent water collected in the beaker glass (5) is clear. The particles then remaining in each of the vessels are collected separately.

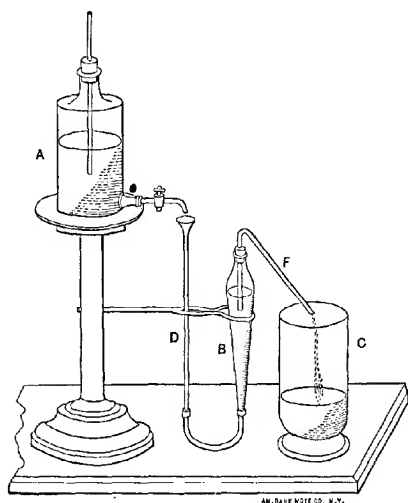


Fig. 36.—Masure's Silt Apparatus.

The author of the method claims that in respect of likeness of particles the results are especially gratifying and that duplicate analyses give results fully comparable. The process, however, has not commended itself to analysts, but it marks a distinct progress toward the principles of later investigators. Had each of the elutriating vessels been placed upright and the rate of flow determined, the apparatus of Dietrich would have served, to a certain extent, for the more rigid investigations of his successors.

243. **Method of Masure.**⁷²—From 10 to 15 grams of the sift-

⁷² *Encyclopédie chimique*, 4 : 137.

ed earth is carefully mixed with 200 cubic centimeters of water. It is then introduced into a doubly conical elutriator B, Fig. 36, of about 250 cubic centimeters capacity. A current of distilled water is allowed to flow from a mariotte bottle A, which secures a regular and constant flow. The bottle A is joined to the elutriator B by means of a rubber tube and the vertical glass tube D, the top of which is expanded into a funnel for the purpose of receiving the water from the mariotte flask. The current of water flowing upward through the elutriator B carries in suspension the most finely divided particles of clay, and these are collected with the emergent water in the receiver C. The sand and coarser particles of clay remain in the elutriator. The water flows out by the tube F, the diameter of which should be less than that of D. When the emergent water becomes limpid the operation is terminated. After the apparatus is disconnected, the water is decanted from the sand in the elutriator, and the whole residue is weighed after drying for two hours at 110° .

The fine soil collected in C may also be separated and weighed, for control, after drying as above.

The pebbles and coarse sand separated by the sieves should also be weighed. By this process the soil is separated into four portions; *viz.*,

(1) Pebbles. (2) Coarse sand. (3) Fine sand and other materials not carried off by the current of water. (4) Fine soil, carried into the receiver C.

244. Method of Schoene.—The method of Schöne⁷³ is based on the combination of a cylindrical and conical separatory tube through which the flow of water is regulated by a piëzometer.

If, in the process of silt separation, the water move perpendicularly upward with a given velocity, *e.g.* $= v$ the separation is dependent:

(1) On the volume of the silt particles, (2) on their specific gravity, and, (3) on their state of disintegration.

If it be assumed that the silt particle is a sphere with a diam-

⁷³ Ueber Schlämmanalyse, Bulletin de la Societe imperiale des naturalistes de Moscow, 1867, 40, First part, 324.

Zeitschrift für analytische Chemie, 1868, 7 : 29.

eter = d , then according to Newton's law of gravity, the following formula would be applied:

$$d = v^2 \left(\frac{3Z}{4g(S-1)} \right).$$

In the above formula Z = a coefficient which depends on the condition of the surface against which the hydraulic pressure or resistance works, in this case a sphere; g = the acceleration of gravity equivalent to 9.81 meter; and S = the specific gravity of the particle.



Fig. 37.—Schöne's Elutriator.

This expression signifies that in a given case, the velocity of the current in the apparatus is just sufficient to counteract the tendency of a given particle to sink. All particles of a smaller diameter, in such a case, will be carried on by the current, while all of a greater diameter would separate by sedimentation. These theoretical conditions are not met with in practice where silt particles of all shapes and degrees of aggregation abound. These particles, whatever their shape, may be said to have the same hy-

draulic value when carried by the same current. It is necessary, therefore, to secure some uniform standard of expression to assume a normal form of particle and a normal specific gravity. For the form, a sphere is evidently the normal which must be considered and for specific gravity that of quartz is taken; *viz.*, 2.65. The mean coefficient for Z may also be placed at 0.55, although slightly different values are ascribed to it. Substituting these values in the formula, it is reduced to the expression; $d = v^2 \times 0.0000255$ (millimeters). It can, therefore, be said that by this or that velocity of the current, silt particles will be removed of this or that diameter, it being understood that all particles of equal hydraulic value to spherules of quartz of the given diameter are included in each class. In order to have the theoretical formula agree with the results of analysis it is necessary to modify it empirically to read $d = v_{11}^2 \times 0.0314$ (millimeter).

This formula is found to agree well with the results obtained for all velocities between 0.1 millimeter and 12 millimeters per second, the ordinary limits of silt separation.

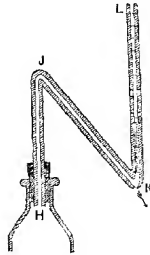


Fig. 38.—Shöne's Elutriator Overflow Tube.

The Apparatus.—The conic-cylindrical elutriating vessel A, B, C, D, E, F, G, Fig. 37, is of glass. The part B, C, is cylindrical, ten centimeters in length and as nearly as possible five centimeters in diameter.

The conical part C, D, is fifty centimeters in length. Its inner diameter at D must not be greater than five centimeters nor smaller than four centimeters.

The bend, D, E, F, should have the same diameter; *viz.*, four to five centimeters.

The part A, B, C, D, and D, E, F, G, may be made of separate parts and joined by a rubber tube.

Outflow Tube and Piëzometer.—The outflow tube and piëzometer, H, J, K, L, are constructed as shown in Fig. 38. Barometer tubing having an internal diameter of about three millimeters is used on the construction of this part of the apparatus. The tube is bent at an angle of 40 to 45 degrees. The knee J must be as acute as possible not to interfere with the inner diameter. The form and especially the magnitude of the outlet are of great importance. It must be circular and nearly 1.5 millimeter in diameter. It must not be larger than 1.67 millimeter nor smaller than 1.5 millimeter. The opening should be so made as to direct the stream of outflowing liquid in the direction shown by the arrow.

The piëzometer L, K, is parallel to the arm H, J, of the delivery tube. Its graduation in centimeters has its zero point in the center of the outlet K. It commences with the one centimeter mark. From one to five centimeters it is divided into millimeters, from five to ten centimeters into one-fourth centimeters, from ten to 50 centimeters into one-half centimeters, and from 50 to 100 centimeters into centimeters. The dimensions given are those required for ordinary soils and for velocities ranging from two-tenths millimeter to four millimeters per second.

For greater velocities, a delivery tube with a larger outlet must be used and the piëzometer must be of greater internal diameter than indicated.

Arrangement of the Apparatus.—The apparatus is conveniently mounted as shown in Fig. 39, giving front and side views of all parts of apparatus in position ready for use. When numerous analyses are to be made much time is saved by having a number of apparatus arranged *en batterie*.

The Sieve.—The soil, before being subjected to elutriation, should be passed through a sieve of which the meshes are 0.2 millimeter square.

The Process.—To measure the diameter of the cylinder, two marks are made with a diamond upon the glass which are distant from each other a certain space, for instance, h centimeters. The

space between these two marks is filled with water exactly measured. Suppose that z . cubic centimeters were used, then the diameter D is determined by the formula:

$$D = \sqrt{\frac{4z}{\pi h}} \text{ (centimeters.)}$$

In order to determine that the elutriating cylinder is strictly comparable in all its parts this measurement should be made upon several parts thereof.

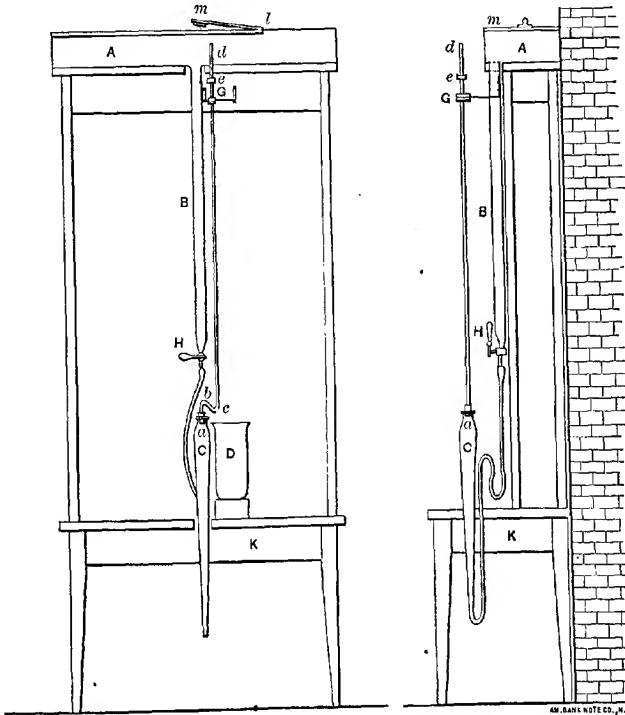


Fig. 39.—Schoene's Elutriator. Arrangement of Apparatus.

The apparatus should now be tested in regard to the quantity of liquid which it will deliver under a given pressure in the pië-

zometer. By means of the stop-cock H the flow of water is so regulated that the outflow at *c* can be measured at a given height of the water in the piëzometer. Suppose that *a* cubic centimeters of water flow in *t* seconds, then the quantity which would flow in one second is determined by the formula, $Q = \frac{a}{t}$ —cubic centimeters. Since according to the law of hydraulic outflow the quantities are proportional to the square root of the height of the column it is easy to compute from any given height the quantity which will flow from any other one desired. For the retardation due to capillary attraction, it is sufficient, in general, to take it as a constant quantity; if this constant quantity be represented by *C*, the observed height of the water in the piëzometer by *h*, and the quantity of water flowing out by *Q*, the data required for any given velocity can be calculated from the following proportion:

$$\sqrt{h_1 - C} : \sqrt{h_2 - C} = Q_1 : Q_2.$$

It is necessary to compute the magnitude of this constant *C* which is to be subtracted. This is accomplished by measuring the quantity of water which flows out at two different heights of the column in the piëzometer. From the foregoing proportion, the value of *C* is as follows:

$$C = \frac{Q_1^2 h_2 - Q_2^2 h_1}{Q_1^2 - Q_2^2} \text{ (centimeters.)}$$

The value of *C* can be the more exactly determined as *h*₁ is greater and *h*₂ smaller. It is best to choose the lowest height from which an exact reading can be made; that is, by which the regular rise and fall of the level of the water in the piëzometer (in consequence of the formation of drops) just begins to disappear. This usually takes place when *h*₂ = 1.5 centimeters to 1.7 centimeter. For the higher value *h*₁ it is best to take about 100 centimeters. Suppose, for example, the following results are obtained:

Observed height.		Observed quantity of outflow.		Height of column to be subtracted due to capillary attraction. C centimeters.
<i>h</i> ₂ centimeters.	<i>h</i> ₁ centimeters.	<i>Q</i> ₁ cubic centimeters.	<i>Q</i> ₂ cubic centimeters.	
80	1.6	5.53	0.406	1.21
100	1.6	6.13	0.484	1.17
80	1.8	5.53	0.406	1.19
100	1.8	6.13	0.484	1.19

The same quantity of water which flows out in a unit of time passes also at the same time over a cross-section of the elutriating cylinder. The diameter of this cylinder being D the equation is derived

$$v = Q - \frac{4}{\pi D^2} \text{ (centimeters.)}$$

Since the velocity in the elutriating cylinder v is directly as the quantity of water overflowing so is

$$v : v_n = \sqrt{h - C} : \sqrt{h_n - C};$$

$$\text{then } v_n = \sqrt{h_n - C} \left(\frac{v}{\sqrt{h - C}} \right)$$

$$\text{and } h_n = v_n^2 \frac{h - C}{v^2} + C. \text{ The constant } \frac{h - C}{v^2}$$

is obtained from the means of a number of estimations; for example as illustrated in the following data:

Observed height, centimeters.	Observed quantity of outflow, cubic centimeters.	Corresponding velocity in elutriating cylinder of 4.489 centimeters diameter, millimeters.	Constant. $\frac{h - C}{v^2}$.
1.6	0.406	0.0257	621
1.8	0.484	0.0306	652
80.0	5.530	0.3490	647
100.0	6.130	0.3870	660
Mean,			645

Then are obtained the following values of h_n and v_n :

$$h_n = 645 V_n^2 + 1.19 \text{ (centimeters)}$$

$$\text{and } v_n = \sqrt{h_n - 1.19} \times 0.0394 \text{ (centimeters.)}$$

In order to be able easily and rapidly to judge under what pressure the outflow has taken place in any particular instance, a large number of values are computed with the help of the formula given and placed together in tabular form. As an example the following table may serve which was computed for one of the apparatus used. Usually it will be sufficient to test the apparatus for four,

different heights and then to interpolate the values for all the others. The numbers marked with a star in the table are those which were determined by experiment; the others were calculated.

Height of column in piezometer. <i>h</i> cm.	Velocity in the elutriating cylinder of 4.489 cm. diameter. <i>v</i>		Corresponding diameter of silt particles. $d = v^{1/11} \cdot 0.0314$ mm. mm.
	Observed, mm.	Calculated, mm.	
1.5	0.222	0.220	0.0120
1.6	0.257*	0.252	0.0131
1.7	0.284	0.281	0.0140
1.8	0.306*	0.307	0.0148
1.9	0.323	0.332	0.0155
2.0	0.346	0.355	0.0162
2.5	0.427	0.451	0.0185
3.0	0.531	0.530	0.0210
3.5	0.577	0.599	0.0227
4.0	0.650	0.660	0.0236
4.5	0.694	0.717	0.0254
5.0	0.751	0.769	0.0265
6.0	0.850	0.864	0.0286
7.0	0.942	0.950	0.0304
8.0	1.050	1.028	0.0320
9.0	1.120	1.101	0.0334
10.0	1.170	1.169	0.0347
15.0	1.490	1.460	0.0400
20.0	1.730	1.710	0.0441
25.0	1.940	1.920	0.0476
30.0	2.100	2.110	0.0506
35.0	2.310	2.290	0.0532
40.0	2.460	2.450	0.0556
45.0	2.610	2.610	0.0578
50.0	2.770	2.750	0.0598
60.0	3.030	3.020	0.0635
70.0	3.290	3.270	0.0667
80.0	3.490*	3.500	0.0697
90.0	3.710	3.710	0.0724
100.0	3.870*	3.920	0.0749

Suppose the problem is, by means of the apparatus tested as above to separate into a number of groups a mixture of silt particles, whose hydraulic values are found between the following diameters: 0.01, 0.02, 0.03, 0.04, 0.05, 0.06, 0.07 millimeters. The table will show at once under what pressure of water the piezom-

eter must be placed in order to give the values; *viz.*, 1.4, 2.8, 7.0, 15.0, 29.0, 53.0, and 83.0 centimeters, respectively.

The apparatus described above, is adapted for velocities in the elutriating cylinder varying from two-tenths millimeter to four millimeters per second. The largest silt particles which can be separated by the velocities given above, have approximately a diameter of 0.08 millimeter. For the separation of larger particles a sieve can take the place of the silt apparatus. If, however, it be desired to subject larger particles to silt analysis, the dimensions of the elutriating cylinder and of the outlet of the delivery tube must be changed accordingly.

Preparation of Sample.—The conduct of silt analysis of natural soils must, in certain cases, be preceded by a special treatment of the sample. If the latter be rich in humus the organic substance must previously be separated as completely as possible. With sandy soils this can be accomplished by ignition. With clayey soils, on the contrary, it is to be performed by boiling the soils at least one hour with water which contains from one to two per cent of free alkali. Soils which contain lime must also be subjected to treatment with dilute hydrochloric acid, and the hydrochloric acid must be as carefully removed as possible before the sample is subjected to elutriation; afterward follows the boiling of the sample in the ordinary way with water. This, of course, can be omitted when it has already been treated with boiling dilute alkali. It is also important to remove the larger particles by a sieve before the elutriation begins. It is well to pass a sample through a sieve after it has been boiled, by which all particles of a larger diameter than 0.2 millimeter are removed. This will usually require about one liter of water and this water should be allowed to rest from one to two hours and poured off with the suspended material which it contains. Only what subsides should be brought into the apparatus. In rinsing the sample as much water must be used as will fill the apparatus up to its cylindrical portion.

After the sample has been placed in the apparatus, the water is allowed to enter slowly, being careful to avoid reaching more than the lowest required velocity, until the outflow begins. The water then is so regulated by the stop-cock as to bring it to the desired

height in the piëzometer. This being accomplished, the different velocities which have been decided upon for separating the particles of silt are used one after the other, as soon as all the silt which can be removed at each given velocity, has been secured. From three to five liters of water will be required for the separation of each class of particles. Sometimes the reading of the height of the water in the piëzometer is difficult; as, for instance, when foam or bubbles accumulate therein. These bubbles can be removed by simply blowing into the tube, or dropping into it a little ether. The outflow of water can be received in vessels, beaker glasses, or cylinders, in which it is allowed to subside. The finest particles which remain in suspension in the water are best determined by difference. If it be desired to weigh them directly, the water can be treated with ammonium bicarbonate until it contains from one to two per cent thereof. The precipitation then takes place in a few hours.

The collection and weighing of silt particles are accomplished in the usual way. That which finally remains in the elutriating vessel is taken out after the end of the operation by closing the stop-cock, removing the stoppers with the piëzometer tube, pouring the contents of the elutriating vessel into a beaker glass and rinsing out carefully all adhering particles. Examples of the working of the apparatus follow:

The soil was taken from the Imperial Russian Agricultural Experimental Institute at Gorki. It was a fine clay sand and was carefully treated with hydrochloric acid. The results of the analysis are given in the following table:

Velocities employed in mm.	Largest diameter of the collected particles in mm.	Percentage of silt product obtained in repeated elutriations.		
0.25	0.012	13.4	12.6	11.9
0.5	0.020	9.1	8.7	9.5
1	0.032	21.0	21.4	20.8
2	0.050	30.4	29.8	31.7
3	0.063	16.7	16.1	15.5
4	0.076	5.3	5.5	5.5
	Residue	4.2	4.9	3.8
	Total	100.0	99.0	98.7

Holthof modifies the apparatus of Schöne by putting into the

lower mouth of the elutriator a little mercury so that the particles of earth are deposited upon its surface and are thus better agitated and washed by the current of water.

245. Mayer's Modification of Schoene's Method.—An improvement of Schöne's apparatus in the direction of greater simplicity has been tested by Mayer⁷⁴ with satisfactory results:

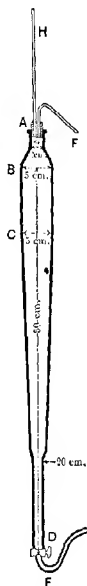


Fig. 40.—Schöne's Apparatus for Silt Analysis. Modified by Mayer.

The apparatus, (Fig. 40), consists of a glass vessel having a glass stop-cock at the bottom for admitting the water. For a distance of 20 centimeters the sides of the tube are parallel and the diameter about one centimeter. Next for a distance of 50 centimeters the tube is conical expanding at a regular rate until the internal diameter reaches five centimeters. For a distance of ten centimeters the vessel is again strictly cylindrical and it is in this cylindrical portion that the separation of the different constituents takes place. The vessel is then rapidly narrowed until

⁷⁴ Journal für Landwirtschaft, 1890, 88 : 162.

at the stopper A it is two centimeters in diameter. This stopper carries two glass tubes, one F bent downward to conduct the overflow into the receiving vessels, and one H for the purpose of regulating the rate of overflow by the height of the column of water therein. The orifice of the overflow tube F should be so regulated that with a pressure of five centimeters water in H, one liter shall pass over in ten minutes.

If the separation be conducted in an apparatus thus mounted and graduated with a pressure of two centimeters in H all that portion of the soil which can properly be called clay will pass over. The fine earth, that is, earth in which all coarse particles have been removed by proper sifting, is used in ten-gram lots for each experiment. The residue, after the separation is complete, consists of pure sand or at least pure sand mixed with humus. Before the fine earth is placed in the apparatus, the calcium carbonate therein is removed with hydrochloric acid. The treatment with hydrochloric acid, however, is not to be recommended in soil containing many undecomposed particles of calcium carbonate or dolomite for then large additions to the silt output might be made from these particles, which could not be regarded as coming from the soil as it actually exists. For alluvial soil, however, previous treatment with hydrochloric acid is recommended unconditionally.

246. Schoene's Method as Practiced by Osborne.—The apparatus used by Osborne⁷⁵ was obtained from Germany and was similar to that described by Schöne in his original paper, except that it was furnished with a second elutriating tube as suggested by Orth. The modification made by Orth consists, essentially, of a second elutriating tube with straight sides into which the bulk of the soil is introduced, only the final part being carried over into the Schöne's tube proper. Water is supplied to the apparatus under constant pressure by means of a mariotte bottle.

The preliminary treatment recommended by Schöne is omitted, as these steps have been shown to be undesirable, on account of affecting the accuracy of the results.

Twenty grams of the air-dried soil are passed, under water,

⁷⁵ Connecticut Agricultural Experiment Station, Annual Report 1887,

through a sieve of one-fourth millimeter mesh. That part of the soil which remains in suspension after being sifted is placed at once in the Schöne tube of the apparatus, the coarser portion being rinsed into the Orth tube. The current is regulated so that the largest particles of quartz carried off have an average diameter of 0.01 millimeter. When all is carried off that can be removed at this rate the current is increased until the largest quartz grains passing off have a diameter of 0.05 millimeter.

As noticed by Hilgard with Schulze's apparatus, secondary currents are formed during the process of elutriation which descend along the walls of the conical portion of the Schöne's tube and some distance along the sides of the cylindrical portion. The tendency of these currents is to produce globular aggregates of particles which fall to the bottom. They are broken up from time to time by increasing the velocity of the current but even this method fails to disintegrate a considerable quantity of them.

247. Statement of Results.—Two samples of soil from the garden of the experiment station analyzed by Schöne's method gave the following proportions of sediment.

In the table the term clay is used to designate all that part of the soil which has diameters less than 0.01 millimeter and which remains suspended after 24 hours standing in water having a depth of 200 millimeters.

SOIL FROM GARDEN OF THE EXPERIMENT STATION.—NOT BOILED.

	<i>A.</i>	<i>B.</i>	<i>C.</i>
Above 0.25 millimeter.....	48.82	48.82	48.82
0.25-0.05 millimeter.....	27.36	29.94	22.37
0.05-0.01 "	8.63	6.07	13.70
0.01 " and less	7.36	7.31	7.20
Clay (by difference)	1.00	1.03	1.08
Loss on ignition	6.83	6.83	6.83
	100.00	100.00	100.00

The column *A* contains the results of the Schöne-Orth method, *B* contains the results of *A* corrected by the beaker method, and *C* represents the average of three direct beaker elutriations according to the method of Osborne.

The differences which these figures show are found to be due to imperfect separation of the finer grades from the coarser and

even when the various fractions separated by the Schöne method are subjected to beaker elutriation and the portions separated from them added to the grades to which they properly belong the Schöne elutriator was found to effect far less exact separations than the beaker method.

Samples of prairie soil from Mercer County, Ill., not boiled, were examined by the two methods with the following results:

	Schöne-Orth elutriation.	Beaker method.
Above 0.25 millimeter	0.76	0.62
0.25-0.05 millimeter	11.25	2.42
0.05-0.01 "	52.65	43.58
0.01 "	14.84	31.58
Clay	4.44	5.81
Loss on ignition.....	14.49	14.49
	98.43	98.50

In this case it is seen that Schöne's method varies considerably from the beaker method and if the beaker method be regarded as correct the Schöne method is evidently less reliable.

In the next table are given the data of the examination of brick clay from North Haven, Conn., by the two methods.

BRICK CLAY FROM NORTH HAVEN, CONN.

	Schöne-Orth elutriation.	Beaker method.
Above 0.25 millimeter	1.02	1.02
0.25-0.05 millimeter	3.91	0.76
0.05-0.01 "	29.63	20.95
0.01 " and less	58.58	71.01
Loss on ignition.....	6.60	6.60
	99.74	100.34

The failure of the Schöne method to give the results obtained by the beaker method is ascribed to the fact that it is impossible for the current of the strength used to disintegrate the clay and further that the particles after they are once separated tend to coalesce by the currents produced by the elutriating process.

248. The Berlin-Schoene Method.—Osborne has also made a study of the Schöne method as modified by the soil laboratory of Berlin. The directions for the analysis by this laboratory method are as follows: . . .

Five hundred grams of the soil are sifted through a sieve with circular holes two millimeters in diameter. Of the earth passing the sieve from 30 to 100 grams are boiled in water with constant

stirring from one-half to one hour or longer, according to the character of the soil. The finer the texture of the soil the smaller the quantity taken and the longer the time of boiling. Treatment with acids or alkalies is not practiced.

The finer portion of the soil remaining suspended in the water, after boiling, is poured into the Schöne tube, the remaining coarse part is rinsed into the Orth tube. The clay, together with the finest sand, is collected in a separate vessel, the water in which it is suspended is evaporated and the residue after drying in the air is weighed. The rest of the operation is carried out as previously described except that the products of elutriation are not ignited but weighed air-dried, in order that they may be further examined, chemically if desired. By proceeding in this manner the following results were obtained:

SOIL FROM GARDEN OF THE EXPERIMENT STATION, BOILED FORTY-FIVE MINUTES.

Separations by the Berlin-Schöne method.		Air-dried.	Ignited.
Above 0.05 millimeter		72.63	71.76
0.05-0.01 millimeter		14.17	12.53
0.01 " and less		12.97	9.38
Loss on ignition .....		...	6.83
		99.77	99.50

For the sake of comparing the mechanical separation attainable by this procedure with those yielded by other methods, the air-dried products were ignited and again weighed and examined.

By subtracting from the ignited portion above 0.05 millimeter, 49.37 per cent, the amount of this soil that remained on a 0.25 millimeter sieve, the fraction between 0.25 millimeter and 0.05 millimeter is found, and the separations in this analysis may be compared with those previously obtained by the beaker method as follows:

SOIL FROM GARDEN OF EXPERIMENT STATION.

	Berlin-Schöne, boiled forty-five minutes.	Beaker method.	
		Boiled twenty-three hours average of four analyses.	Not boiled nor pestled, average of three analyses.
Above 0.25 millimeter	49.37	47.77	48.82
0.25-0.05 millimeter	21.39	20.75	22.44
0.05-0.01 "	12.53	11.18	12.55
0.01 clay included	9.38	13.47	9.36
Loss on ignition	6.83	6.83	6.83
	99.50	100.00	100.00

Osborne concludes from the above facts that the Berlin-Schön method, while showing close agreement with the beaker method does not give results which are identical with that method. On subjecting portions separated by the Berlin-Schöne method to the beaker analysis additional separations were secured. In the case of heavy loams the inability of the Berlin-Schöne method to effect even a rough or approximate separation of the several grades becomes very conspicuous.

The latest form and methods of manipulations for the process vary but little from the foregoing details.⁷⁶

This method has been in use in the Royal Prussian Geological Survey for 25 years and is highly recommended as reliable and satisfactory.

249. Method of Hilgard.—Two important principles lie at the foundation of this method; *viz.*, 1, the use only of separating vessels of true cylindrical shape and 2, the employment of a mechanical stirrer to break up the floccules formed during the process of separation. The points in the apparatus to be considered are uniformity of the cross-section of the elutriator at every point exact perpendicularity of position, careful control of the rate of flow and continuous operation of the mechanical stirrer. According to Hilgard's observations the stirring due to the current of water alone is not sufficient to break up the floccules unavoidably formed during the separation, while any inclination of the sides of the elutriating vessel from the perpendicular due either to a conical shape or false position favors in the highest degree the formation of floccules due to reflex currents formed in the body of the liquid.

In order to carry out the idea suggested by Türschmidt of substituting for the accidental and indefinite products usually appearing in the statements of silt analyses sediments of known and definite hydraulic value a constant head of water is used, secured by means of a mariotte bottle connecting with the tube delivering the current through a cock provided with an arm moving on a graduated arc.

According to Hilgard the separation of sediments by the meth-

⁷⁶ Wahnschaffe, *Wissenschaftliche Bodenuntersuchung*, Second edition 31 and 40.

od of subsidence does not possess the analytical accuracy of the moving liquid method, especially when the latter is combined with mechanical stirring. The subsidence method requires close and continuous attention and in the case of fine sediments tending to flocculation the difficulties of the method are greatly increased. The views of Hilgard in respect of the laboriousness of the subsidence method lose, however, some of their force since the modifications of Osborne have come into use. The simplicity and cheapness of the apparatus required for subsidence give it at the start many advantages over the more elaborate process with a churn elutriator. For rigid scientific investigation, however, the method of Hilgard is commended as a standard of comparison in all cases.

There is one important point in which the separation of the silt particles by translation with water has a great advantage over any method of sedimentation; *viz.*, in the former the particle to be freed and separated is carried in a direction where it meets constantly, decreasing numbers of particles and thus the tendency to collide and coalesce is constantly weakened.

250. The Elutriator.—The instrument devised by Hilgard¹⁷ for the purpose of breaking up these flocculent aggregates is shown in Fig. 41, and a simpler form of Schöne's elutriator, in Fig. 42, which can serve for grain sizes above eight millimeters hydraulic value. The latter is conveniently selected so as to have half the cross-section of the former, so that with the same position of the index lever the velocity will be just doubled. The cylindrical glass tube, 2 Fig. 41, of about forty-five millimeters inside diameter at its mouth, and 290 to 300 millimeters high, has attached to its base a rotary churn consisting of a brass cup, shaped like an egg with point down, so as to slope rather steeply at base, and thrice perforated; *viz.*, at the bottom for connection with the relay reservoir, and at the sides for the passage of a horizontal axis bearing four grated wings. This axis, of course, passes through

¹⁷ Bulletin 38, Bureau of Chemistry, Department of Agriculture, 60.

Proceedings American Association for the Advancement of Science, Portland (22nd) meeting, 1873, 54 et seq.

Proceedings of the 8th Annual Meeting of the Society for the Promotion of Agricultural Science, 1887, 48 et seq.

stuffing boxes, provided with good thick leather washers, saturated with mutton tallow. These washers, if the axis runs true, will bear a million or more revolutions without material leakage. When a leakage is noted additional washers may be slipped on without emptying the instrument, until the analysis is finished. For the finest sediments, from five to six hundred revolutions per minute is a proper velocity, which may be secured by clock work, turbine or electric power. The driving pulley should not be directly connected with the axis, both because it is liable to cause leakage, and because it is necessary to be able to handle the

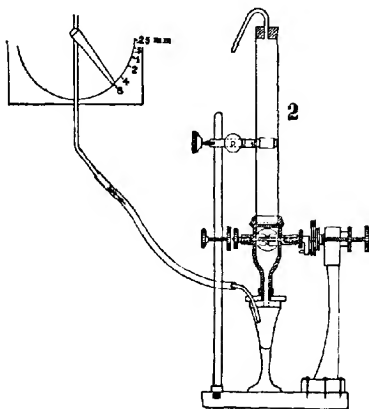


Fig. 41.—Hilgard's Churn Elutriator.

elutriator quickly and independently. The indirect connection is accomplished by the use of "dogs" on the pulley and churn axis. For the grain size of one to eight millimeters hydraulic value lower velocities are sufficient; too low a velocity causes an indefinite duration of the operation and may be recognized by the increase of turbidity as the velocity is increased.

As the whirling agitation caused by the rotation of the dasher would gradually communicate itself to the whole column of water and cause irregularities, a wire screen of 0.8 millimeter aperture is cemented to the lower base of the cylinder.

The relay vessel should be a thick, conical test glass with foot; its object is to serve as a reservoir for the heavy sediments not concerned at the velocity used in the elutriator tube, and whose presence in the latter or in its base, the churn, would cause abrasion of the grains and changes of current velocity such as occur in the apparatus of Schöne. It is connected above with the churn by a brass tube about ten millimeters in clear diameter, so as to facilitate the descent of the superfluous sediments, which the operator, knowing the proportion of area between the connecting tube and elutriator, can carry to any desired extent; thus avoiding the disturbance of the gauged current velocities, as well as all material abrasion.

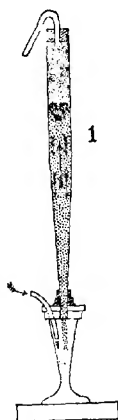


Fig. 42.—Improved Schöne's Apparatus with Relay.

A glass delivery tube should extend quite half way down the sides of the relay vessel, to insure a full stirring up of the coarse sediments when required. By means of a rubber hose, not less than 20 inches in length, this delivery tube connects with the siphon carrying the water from near the bottom of the Mariotte bottle, conveniently made of a ten-gallon acid carboy. A stopcock provided with a long, stiff index lever, moving on an empirically graduated arc, regulates the delivery of water through the siphon. Knowing the area of the cross-section of the elutriator tube, the number of cubic centimeters of water which should

pass through it in one minute, at one millimeter velocity, is easily calculated, and from this the lever positions corresponding to other velocities are quickly determined and marked on the graduated arc. The receiving bottle for the sediments must be wide and tall, so as to allow the sediment to settle while the water flows from the top into the waste pipe.

Thus arranged, the instrument works very satisfactorily, and by its aid soils and clays may readily be separated into sediments of any hydraulic value desired. But in order to insure correct and concordant results, it is necessary to observe some precautions; *viz.*,

(1) The tube of the instrument must be as nearly cylindrical as possible and must be placed and maintained in a truly vertical position. A very slight variation from the vertical at once causes the formation of return currents, and hence of molecular aggregates on the lower side.

(2) Sunshine, or the proximity of any other source of heat, must be carefully excluded. The currents formed when the instrument is exposed to sunshine will vitiate the results.

(3) The mariotte bottle should be frequently cleansed, and the water used be as free from foreign matters as possible. For ordinary purposes it is scarcely necessary to use distilled water. The quantities used are so large as to render it difficult to maintain an adequate supply, and the errors resulting from the use of any water fit for drinking purposes are too slight to be perceptible, so long as no considerable development of the animal and vegetable growths is allowed. Water containing the slimy filaments of fungoid growths and moss prothalia, algæ, vorticellæ, etc., will not only cause errors by obstructing the stop-cock at low velocities, but these organisms will cause a coalescence of sediments that defies any ordinary churning, and completely vitiates the operation.

(4) The amount of sediment discharged at any time must not exceed that producing a moderate turbidity. Whenever the discharge becomes so copious as to render the moving column opaque, the sediments assume a mixed character, coarse grains being, apparently, upborne by the multitude of light ones whose hydraulic value lies considerably below the velocity used, while

the churner also fails to resolve the molecular aggregates which must be perpetually reforming where contact is so close and frequent. This difficulty is especially apt to occur when too large a quantity of material has been used for analysis, or when one sediment constitutes an unusually large portion of it. Within certain limits the smaller the quantity employed the more concordant are the results. Between ten and fifteen grams is the proper amount for an instrument of the dimensions given above.

251. Preparation of the Sample.—In some cases simple sifting will be sufficient to prepare the air-dried soil for the elutriator. In most cases, however, some mechanical aid must be invoked to secure particles of sufficient fineness. Nothing harder than a rubber pestle should be used and care must be taken not to break up any calcareous or ferruginous masses which the particles of fine soil may contain. The use of water in this mechanical attrition should be avoided, if possible, but in some heavy clay and adobe soils wetting becomes necessary. In this case the parts separated by the sieve are collected separately and the turbid mass removed by water and dried for further examination.

A sieve of 0.5 millimeter mesh is recommended as the best because that is almost exactly the diameter of the particles passing off at the maximum velocity of 64 millimeters per second to which the elutriator is adapted. The particles passing the 0.5 millimeter mesh are called fine earth.

252. Preparation by Boiling.—The method of preparation by boiling may be applied to all samples of fine earth. The fact pointed out by Osborne, that the diffusibility of some clays is diminished by long boiling, renders it important to restrict the time of this operation as much as possible. With most soils from eight to 15 hours will be long enough, occasionally extending to even 24 hours. A thin long-neck flask of about one-liter capacity should be used; filled three-quarters full with distilled water and the sample of soil added. The flask is supported over the lamp on a piece of wire gauze at an angle of 45°. It carries a cork with a long condensing tube. At first the boiling goes on smoothly, but after a time violent bumping may supervene, endangering the flask but promoting the object in view.

The contents of the flask are transferred to a beaker and diluted with distilled water to one and a half liters, shaken and allowed to settle for a time necessary to allow all particles of 0.25 millimeter hydraulic value to reach the bottom. The supernatant turbid liquid is decanted and the process repeated with smaller quantities of water until no further turbidity is produced. The united waters, of which there will be from four to eight liters, are well shaken and a proper time allowed for the 0.25 millimeter hydraulic value sediments to fall. This last step is necessary to remove any such sediments which may have been carried over mechanically in the first separation. The dilution being very great, a fairly perfect separation is thus secured and the sediments are then ready for the elutriator.

253. Separation of Clay and Fine Silt.—The property which pure clay possesses, of remaining suspended almost indefinitely in pure water, affords a ready means of separation from the silt particles of less than 0.25 millimeter hydraulic value. But the finest silt particles subside so slowly that this method of separation is too long to become practically applicable to secure a perfect demarcation between the finest silt and so-called colloidal clay.

Hilgard recommends the following procedure: The clay water from the previous separation is placed in a cylindrical vessel of such a diameter as to allow the column of water to be 200 millimeters high where it is allowed to settle for 24 hours. When the clay is very abundant a longer time may be allowed; *viz.*, from 40 to 60 hours. The line of separation between the dark silt below and the translucent clay above is sharply defined. Finally the clay water is decanted and the remaining liquid poured off leaving the sediment as sharply defined as possible. The sediment is rubbed with a rubber pestle and a few drops of ammonia water added. Distilled water is added, the beaker well shaken or stirred to break up the floccules that may have formed and subsidence permitted as before. This operation is repeated from six to nine times until the water remains quite clear after subsidence or the decanted turbid water fails to be precipitated by brine showing the suspended matter to be fine silt and not clay.

The diameter of the particles of silt thus obtained is from 0.001 to 0.02 millimeter, and is impossible to obtain it quite free from any admixture with clay.

254. Estimation of the Colloidal Clay.—The importance of the colloidal constituent of the clay is such as to make its direct determination desirable. The volume of the clay waters at this stage of the analysis may amount to 20 liters. One method of determination consists in evaporating an aliquot portion and this method will yield good results if the sample be free from soluble salts and the quantity taken be not too small. At least 500 cubic centimeters should be used for this purpose. A better method consists in precipitating the clay by means of a saline solution. A saturated solution of salt is recommended for this purpose of which 50 cubic centimeters are sufficient to precipitate the clay from one liter of the clay water. The precipitation is hastened by heating. Each portion of the clay water should be precipitated as soon as obtained, the total volume of the precipitate at the end of 24 hours is thus reduced to a minimum. The clay water from the succeeding separations of the same analysis can be mixed with the precipitate which diffuses therein, thus promoting the precipitation of the rest of the clay inasmuch as the separation takes place more readily where more clay is present. When all the clay is thus collected it can be gathered on a tared filter and washed with weak brine. Pure water may not be used because of the diffusibility of clay therein. After drying at 100° and weighing it is washed with a weak solution of ammonium chlorid until all sodium is removed. The filtrate is evaporated to dryness, ignited at low redness, and weighed. The weight of the sodium chloride thus obtained plus the weight of the filter deducted from the total weight gives the weight of the clay precipitate. Whenever the clay collected as above will not diffuse in water it may be washed with water and its weight directly obtained. An excess of iron in clay will usually allow of the above treatment.

255. Properties of Pure Clay.—The percentage of pure clay as obtained by the procedure described is about 75 in the finest natural clays, 45 in heavy clay soils, and 15 in ordinary loamy soils.

When freshly precipitated by brine it is gelatinous resembling a mixed precipitate of iron and aluminum oxids. Its volume greatly contracts on drying, clinging tenaciously to the filter, from which it may be freed by moistening. On drying, it becomes hard, infriable, and often resonant. It usually possesses a dark brown tint due to iron oxid. Under the action of water it swells up like glue, the more slowly as the percentage of iron is greater. In the dry state it adheres to the tongue with great tenacity. The particles composing this colloidal clay remaining in suspension as described are extremely minute. With a magnifying power of 350 diameters Hilgard states that no particles can be discerned.

256. Chemical Nature of the Fine Clay.—The fine particles separated as above consist essentially of hydrous aluminum silicate or kaolinite. It doubtless contains, however, other colloids or hydrogels whose absorptive powers are similar to those of clay. It appears also to contain sometimes free aluminum hydroxid, and colloidal ferric hydroxid, and amorphous zeolitic compounds.

While the most careful mechanical separation can give at best only approximately the really plastic kaolinite substance, yet it is far closer than that attained by determination of total alumina with boiling sulfuric acid. By the latter treatment all the lime-kaolinite particles are decomposed and the method does not lead to even an approximate estimate of the soil's plasticity.

257. Separation of the Fine Sediments.—The sediments remaining after the separation of the clay and fine silt are ready for separation in the churn elutriator. The apparatus mounted, as already described, is brought into use by beginning with a low velocity of the water in the upright tube. The rate of flow should be set at from 0.25 millimeter to 0.50 millimeter per second, and the churn put in motion.

When the elutriating tube is partly full of water the sediments should be poured in from a small beaker which is perfectly cleaned by means of a washing flask. The stopper and delivery tube of the elutriator are then put in place. The rate of flow should be so regulated that the sediments shall have had a few seconds of

subsidence before the water is within thirty millimeters of the top. At this point the required velocity for the first sedimentation should be turned on; *vis.*, 0.25 millimeter per second. At first the sediment passes off rapidly and the water in the elutriator is distinctly turbid. This excess of turbidity ceases in a few hours and then some attention is necessary in order to determine when the process is complete. In fact it never is completely finished, but where no more than one milligram of silt comes off with one liter of water it may be said to be practically done. The time required for the first operation varies from 15 to 90 hours. Downward currents in the elutriator are likely to form in spite of all precautions, and floccules of silt adhere to its walls. These should be detached from time to time with a feather in order to bring them again in contact with the churn.

Hilgard has found that, practically, 0.25 millimeter per second is about the lowest velocity available within reasonable limits of time, and that by successively doubling the velocities up to 64 millimeters a desirable ascending series of sediments is obtained; provided always, that a proper previous preparation has been given to the soil or clay. It would seem that according to the prescription given above for the preliminary sedimentation, no sediment corresponding to 0.25 millimeter velocity should remain with the coarser portion. That such is nevertheless always the case, often to a large percentage, emphasizes the difficulty, or rather impossibility, of entirely preventing or dissolving the coalescence of these fine grain sizes by hand stirring, as in beaker elutriation. It is only by such energetic motion as is above prescribed that this can be fully accomplished, and the delivery of 0.25 and 0.50 millimeter hydraulic value really exhausted.

It is desirable to run off the upper third of the column at intervals of from 15 to 20 minutes by temporarily increasing the velocity. Recent sediments, river alluvium, etc., are more easily separated than soils of more ancient formation. The second, third, etc., separations are naturally accomplished in much less time than the first. The respective velocities of the separations should be 0.25 millimeter, 0.50 millimeter, one millimeter, two millimeters, four millimeters, eight millimeters, 16 millimeters, 32

millimeters, and 64 millimeters a second. Below a velocity of four millimeters a second the mechanical stirrer is indispensable. Above this velocity the current of water in the conical base will be sufficient to bring the desired particles into the ascending column. At this velocity also a smaller elutriating tube having one-half or one-quarter the cross-section of the first may be employed to hasten the operation and diminish the quantity of water required. The quantity of water required for a complete separation is from 100 to 120 liters. Any soft water free of organic matter may be used, but distilled water is best. Hard water should be avoided.

The mean time required for the different separations is as follows: 0.25 millimeter hydraulic value, 35 hours; 0.50 millimeter hydraulic value, 20 hours; one millimeter hydraulic value, seven and a half hours; two to sixty-four millimeters hydraulic value, eight hours. With proper arrangements for night work, an analysis may be finished in three or four days not counting the time required for the previous separation of the clay.

258. Weighing the Sediments.—The sediments should be dried at the same temperature used for drying the soils. Hilgard dries both at 100°. Great care should be used in weighing the exceedingly hygroscopic clay sediments. In the case of the sediment of 0.25 millimeter hydraulic value it is allowed to subside as much as possible and after removing the supernatant water the residue, from 25 to 50 cubic centimeters, is evaporated in a platinum dish and weighed therein. The water can be completely decanted from the other sediments, and they can be dried and weighed without any unusual precautions.

The loss in the separation of clays and subsoils containing but little organic matter is usually from 1.5 to 2 per cent. This loss is partly due to the fine silt which comes off during the whole of the process and which is lost in the decanted waters of the sediments of 0.25 millimeters hydraulic value and above. The procedures indicated above are not strictly applicable to soils rich in humus and other organic matters, but the destruction of these matters by ignition leaves the residual soil in a condition wholly unfit for sedimentary separation.

259. Classification of Results.—A convenient method of stating the results of an analysis may be seen from the following classification. The percentage obtained for each of the classes is to be entered in the column provided for that purpose.

	No.	Names of silt classes.	Diameter of grains in millimeters.	Velocity of current millimeters hydraulic value.	Per cent.
Elutriator without churn. Sieves.	1.	Grits.....	1 -3	....	} 2.07
	2.	Fine grits.....	0.5-1	....
	3.	Coarse sand.....	0.50	64	} 0.55
	4.	Medium sand.....	0.30	32	
	5.	Fine sand.....	0.16	16	
	6.	Finest sand.....	0.12	8	0.21
Elutriator with churn.	7.	Coarse silt.....	0.072	4	1.21
	8.	Large silt.....	0.047	2	2.92
	9.	Medium silt.....	0.036	1	7.36
	10.	Silt.....	0.025	0.5	8.86
Beaker sedimentation.	11.	Fine silt separated in elutriator...	0.016	0.25	7.85
	12.	Fine silt separated from clay water.	0.010	<0.25	35.22
	13.	Clay.....	....	<0.0023	33.16
Total.....					99.36

The measurements of diameters in the above table is of the best formed quartz grains in each class. Naturally the actual size of the particles may vary in each class within the extreme limits of the diameter next above and below. It is not easy to indicate in popular language distinctions not popularly made but the grades of particles designated by the names grits, sand and silt, may serve, at least, to establish uniformity of expression. The term grits is thus applied to all grains above one millimeter in diameter up to gravel. Below one millimeter down to 0.1 millimeter may be called sand and below that silt may designate the particles down to an impalpable powder.

260. Influence of Size of Tube.—The diameter of the elutriating tube exerts a sensible influence on the character of the sediments. The friction against the sides of a small tube is comparatively greater than in a large tube. Strictly speaking, no class of sediments strictly corresponds to the hydraulic value calculated from the cross-section of the tube and the quantity of water supplied thereto. The sediments correspond actually to higher velocities, due to the fact that the lateral friction causes a more rapid flow

in the center of the water column. This may be demonstrated by slightly diminishing the velocity while a sediment is copiously discharging. The turbid column then remains stationary while clear water is running off.

261. Statement of Results.—A complete silt analysis of a soil, conducted by the method of Hilgard, depends largely for its practical value on an intelligible tabulation. The method of collating results is illustrated in the table of analyses of Mississippi soils.⁷⁸

The character of the soils entering into the given analyses is as follows:

Nos. 248, 206, 209, 397, 219, belong to the end of the drift period.

No. 230 is one of the two chief varieties of soils occurring in what is known as the flat-woods, a level surface bordering on the cretaceous area, having lower tertiary clays near the surface.

No. 165 is a light soil which occurs in the former in irregular strips and patches, is easily tilled, absorbs rain water readily, but is subject to drought and does not hold manure.

No. 248 is from a soil stratum three feet thick. The soil is so light that the finer particles of it are carried away by high winds.

Nos. 206 and 209 are typical of the soils producing the long-leaf pine. This soil is much improved by an admixture of the subsoil No. 209, which enables it to hold manure.

No. 219 is a cotton upland soil of the best quality, found in Western Mississippi and Tennessee.

No. 397 is the same soil of a second rate quality. These lands are easily washed into gullies on account of their lack of perviousness to water. They also easily swell up in contact with water, and become thereby readily diffused. The denudations produced by heavy rains are rapidly destroying the lands covered by these soils.

No. 173 is a sedimentary or residual subsoil of the cretaceous prairies of Northeastern Mississippi, forming a stratum from three to seven feet thick.

⁷⁸ Association for the Advancement of Science, Portland (22nd) meeting, 1873: 72.

SILT ANALYSIS OF MISSISSIPPI SOILS AND SUBSOILS.

Designation of materials.		Diameter. (Millimeters.)	Velocity (hydraulic value). Millimeters per second.	Upland.					Mississippi bottom.						
				Yellow loam.					Champlain.						
				Sandy.		Loam.		Clay.		Swamp river.		River deposit.		Modern.	

No. 230 is a residual soil which is formed by the disintegration of the old tertiary clays. It yields good crops only in very favorable years, and is easily injured both by wet and dry seasons.

No. 246 is a soil of the same origin, but is more easily tilled than the foregoing, does not crack, but becomes very hard when dried slowly. Its superiority to the former soil as regards tillage consists in the presence of the large amount of iron and lime.

No. 196 is a typical heavy clay soil; is better suited for the potter than the farmer. It cracks on drying, whence its popular name. On the accession of rain the edges of these cracks crumble and fall, until finally the lumpy surface is produced which is locally known as hog wallows.

No. 390, the richest soil of the Yazoo Bottom, seems to have a physical composition like the preceding one. Its superiority is due not only to the increased quantity of plant food which it contains, but to its property of crumbling on rapid drying. Even when plowed wet, on drying each clod crumbles into a loose pile resembling buck-shot; whence its name. It is strongly calcareous.

As comparative data, are added the soils 365, 377, and 395, representing alluvial deposits, and two deposits from the Delta of the Mississippi.

262. Comparison of Osborne's Method with Hilgard's Method.^{7a}

—The comparative results obtained by Osborne's method, beaker elutriation, and Hilgard's method, churn elutriation, are given in the following tables:

SOIL, FROM EXPERIMENT STATION GARDEN, NEW HAVEN CONN.
SURFACE SOIL, BOILED TWENTY-THREE HOURS.

Diameter in millimeters.	Churn elutriation.		Beaker elutriation.
	Per cent.	Per cent.	Average of four analyses. Per cent.
Removed by sieves.....	47.77	47.77	47.77
0.25-0.05.....	22.06	21.95	20.75
0.05-0.01.....	11.20	11.62	11.18
<0.01.....	9.82	9.14	10.72
Clay (difference).....	2.32	2.69	2.75
Loss on ignition.....	6.83	6.83	6.83
	100.00	100.00	100.00

^{7a} Connecticut Agricultural Experiment Station Annual Report, 1886; 141.

SUBSOIL, BOILED TWENTY-THREE HOURS.

Diameter in millimeters.	Churn elutriation.		Beaker elutriation.	
	Per cent.	Per cent.	Per cent.	Per cent.
Removed by sieve...	39.33	39.33	39.33	39.33
0.25-0.05	33.61	30.83	32.35	32.95
0.05-0.01	10.91	12.25	10.32	10.37
<0.01	7.05	8.11	8.29	7.64
Clay..	5.02	5.40	5.63	5.63
Loss on ignition	4.08	4.08	4.08	4.08
	100.00	100.00	100.00	100.00

These analyses, conducted with sandy soils, agree quite as well as could be expected from two such different methods, and from the further fact that the beaker analysts were not accustomed to the use of the churn elutriator.

Elutriation of Clayey Soils.—Hilgard found that by churn elutriation no satisfactory results could be obtained on clay without long boiling and subsequent kneading of the finer sediments. Osborne examined a sample of clay by his method after previous boiling for 23 hours. When the sediments were examined by the microscope they were found to contain many aggregations of particles which broke into dust under the pressure of the thin glass slide-cover. These sediments were then gently crushed in the beaker with the help of a soft rubber stopper with a glass rod for a handle, the grinding together of the particles being, as much as possible, avoided. This pestling was continued with clear water as long as it occasioned turbidity. Comparison of the analyses shows that practically identical results were obtained on this soil whether it was boiled or not and indicates that the sediments are reduced to their elements by gentle pestling alone. For such soils, therefore, it is demonstrated that pestling is a much safer treatment than boiling. The same remark may be applied to the fertile prairie soil of Mercer County, Illinois, where boiling proved quite insufficient and in which the pestling process proved completely successful. The general conclusions arrived at from the results obtained by Osborne are as follows:

1. On sands and silts of pure quartz or similar, resistant material Hilgard's method and beaker elutriation give practically identical results.

2. With coarse sands and silts upon whose grains finer matter has been cemented by silicates, etc., and with soils containing soft slaty detritus, the churn elutriator with preliminary boiling may give results too low for the coarse and too high for the finer grades. In these cases beaker elutriation with pestling yields more correct figures.

3. Some loamy soils containing no large amount of clay or of extremely fine silt, as well as prairie soils rich in humus, cannot be suitably disintegrated by twenty-four hours' boiling, but are readily reduced by pestling.

4. Beaker elutriation preceded by sifting, gives results in five or six hours with use of from two to three gallons of pure water, which, in churn elutriation, require several days and consume from eight to ten gallons of pure water.

5. Hilgard found that practically 0.25 millimeter is about the lowest velocity of water current per second available within reasonable limits of time in his elutriator. Such a current carries over particles up to 0.015 millimeter diameter and hence the silts of less dimensions cannot be conveniently separated by churn elutriation. In beaker elutriation there is no difficulty in making good separations at 0.01 millimeter and at 0.005 millimeter.

6. Beaker elutriation requires no tedious boiling or preliminary treatment and with careful pestling of the sediments gives, we believe, as nearly as possible, a good separation of adhering particles and at every stage of the process carries with it, in the constant use of the microscope, the means of testing the accuracy of its work and of observing every visible peculiarity of the soil. It is not claimed that pestling may not easily go too far, but in any case a good judgment may be formed of its effects and of the extent to which it is desirable to carry it.

7. In beaker elutriation the flocculation of particles occasions little inconvenience and does not impair the accuracy of the results, inasmuch as the flocculated particles are easily broken up.

263. Comparison of the Osborne with the Schloesing Method.—Schlösing's method has been compared by Osborne⁸⁰ with the beaker method of elutriation applied to the "sand" obtained by

⁸⁰ Connecticut Agricultural Experiment Station, Annual Report, 1887:

the Schlösing method with results which show that this product is capable of separation into groups of very different value.

With the prairie soil from Mercer County, Illinois, the following results were obtained working on the original sample and the sand separated by the Schloesing process:

SCHLOESING'S METHOD.

	Per cent.
Calcium carbonate	0.88
Humus	1.57
Loss at 150° C.	4.42
Sand	82.86
Clay.....	7.86
	<hr/> 97.59

BEAKER METHOD.

	Schloesing's sand.		Original soil. Ignited, per cent.
	Dried at 150° C., per cent.	Ignited, per cent.	
Above 0.25 millimeter diameter..	0.12	0.10	0.92
0.25-0.05 millimeter diameter....	3.58	3.55	2.89
0.05-0.01 millimeter diameter....	42.69	41.87	42.86
0.01-0 millimeter diameter	23.66	20.47	37.44
Clay	12.81	10.14	
Clay .....	....	....	7.40
Loss on ignition .....	....	6.73	14.49
	<hr/> 82.86	<hr/> 82.86	<hr/> 100.00

The "clay" obtained by the Schlösing method contained but little sand and in this respect the separation was satisfactory. The "sand," however, contained a considerable amount of clay. The data show that the textural character of the soil is greatly changed by the boiling with acids which the Schlösing method requires. The treatment with acid has disintegrated the particles of less than 0.01 millimeter diameter so that one-third of this portion appears as clay, according to the Hilgard method of estimating clay, which is the one employed.

As to the humus it may be noted that the loss in the analysis by Schlösing's method; *viz.*, 2.41 per cent, plus loss at 150° = 4.42 per cent, plus humus found = 1.57 per cent, plus carbon dioxide ($\frac{44}{88}$ of 0.88 =) 0.69 per cent amounts to 9.09 per cent, while the loss on ignition which represents humus, carbon dioxide and water

is 14.49 per cent. The 5.40 per cent difference must evidently be, for the most part, humus which has escaped estimation by the Schlösing method, having been distributed among the sand and clay.

264. The Mechanical Determination of Clay.—Schlösing's method for the separation of the clay as stated by Osborne⁸¹ is essentially one of subsidence for 24 hours from a volume of from 200 to 250 cubic centimeters of water, but of no specified height. Hilgard's conventional method requires the same time and a height of solution of 200 millimeters.

Such methods of separation assume, first, that most of the sand and, second, that little of the clay shall settle within the fixed time. That both of these assumptions are fallacious, the following experiments show. The clay obtained by twenty hours subsidence from thirty grams of brick clay is suspended in four liters of distilled water and allowed to settle out completely, which requires several days. The water is then decanted to remove all soluble matters, the jar again filled with distilled water, and the clay and fine sand again allowed to settle for several days. The upper three-quarters of the liquid are then decanted and made up to a volume of four liters, and this is allowed to stand several days, when a considerable sediment forms. A decantation is again made as before. The operations are repeated until the clay water has been so far freed from the clay as to become opalescent; then it first ceases to deposit any appreciable sediment. A microscopic examination of the several sediments thus collected shows them all to contain particles of sand. It appears, therefore, that only after the liquid containing the clay has become opalescent does it cease to deposit fine particles of sand as well as of clay.

Furthermore, the character of the true clay itself is so changed under certain conditions that it loses the property of remaining in prolonged suspension in water, as is shown by the following treatment:

A sample of clay which has been freed from particles of sand exceeding 0.005 millimeter diameter is suspended in water and

⁸¹ Connecticut Agricultural Experiment Station, Annual Report, 1887, •157.

precipitated from it by freezing. It is then washed by decantation with alcohol and dried in the air. A portion of this clay is shaken with water and allowed to stand a few hours, during which time the greater part of it has settled. After decanting the water and suspended clay and repeating this process a few times, a very considerable part of the clay is left which will subside completely through 100 millimeters in a few hours. After standing under water for several months, only a small part of the clay has regained the quality of prolonged suspension. It has been found, however, that if this clay be pestled, this quality of prolonged suspension is restored to it to a very considerable degree. This fact seems to indicate that incipient flocculation is the cause of the more rapid sedimentation, but this is not mentioned by Osborne.

It is evident, therefore, that conventional methods depending on simple subsidence can give no accurate results because the ever varying amounts of finest sand and clay in different soils yield variable mixtures of the two when subjected to any simple course of treatment by elutriation and subsidence.

The method of persistent pestling and repeated subsidences and decantations continued until no further separation can be effected, although extremely tedious, is the only one which has so far yielded even approximately good separations on any of the clayey soils examined by Osborne.

A single subsidence of the clay water for 24 hours will free it from all particles of sand having a diameter greater than 0.005 millimeter, but in many cases a considerable amount of finer sand will remain in suspension for many hours or days.

On the other hand, the sediment formed during the 24 hours subsidence will not be free from clay, as may be easily seen by suspending it in water a second time and allowing it to stand again for 24 hours. Both Hilgard and Schlösing direct attention to these defects, but assume that they do not usually influence the results to a sufficient extent to deprive them of value. In many cases this is undoubtedly true, as, for example, in such soils as that from the garden of the Experiment Station, at New Haven, in which there is but little clay and fine sand; but in soils

of the opposite character, as in the North Haven brick clay where exact separations are most desirable, a very considerable error is thus inevitably encountered.

265. Effect of Boiling on the Texture of Clayey Soils.—Most investigators who have worked upon mechanical soil analysis advise boiling with water in order to detach clay and sand from each other and make a good separation of the several mechanical elements practicable or possible. In general, however, the instructions as to the time and manner of boiling are rather indefinite, and no definite research as to the effects of this treatment has been undertaken.

The practice of Hilgard, to boil 24 hours or even longer in case of adhesive clays, according to Osborne⁸² appears to be objectionable in view of the dehydration and change of physical properties known to occur in case of many hydroxids, especially those of iron and aluminum, which may be present in the soil. It is a familiar fact that the hydroxids above named and many other amorphous substances when precipitated from cold solutions are more bulky and less easily washed upon a filter than when thrown down hot. It is also well known that their properties are considerably changed by warming or boiling with water. Heating with water to boiling for some hours or days gradually converts the bulky brown-red ferric hydroxid, which when precipitated cold and air-dried for 18 days has been found to contain 38 per cent. of water, into a much denser, bright red substance containing but two per cent of water. St. Gilles has also observed the partial dehydration of aluminum hydroxid from $\text{Al}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$ to $\text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$ by prolonged boiling.

The hydrate of silica and the highly hydrated silicates are most probably affected in a similar manner, and if such be the case, boiling would evidently change the constitution of clay in a very essential degree.

The following experiments throw light on this subject:

Ten grams of North Haven brick clay were boiled continuously for nine days with about 700 cubic centimeters of distilled

⁸² Connecticut Agricultural Experiment Station, Annual Report, 18 87 : 159.

water, in a glass flask of one liter capacity and furnished with a reflux condenser. Fifteen grams were boiled in the same manner for eight and one-half days. When the boiling was concluded, the soil was found to have assumed a granular condition, the clay and fine sand being collected into a mass of small grains resembling coarse sand and settling rapidly. One portion thus boiled was elutriated by the beaker method, the other by Hilgard's. The pestle was not used on either of those portions as it was desired to determine simply the effect of prolonged boiling. The separations thus accomplished are here compared with the elutriations of the same soil boiled 23 hours and of the pestled but unboiled soil.

Diameter of particles.	Hilgard elutriation.		Beaker elutriation.	
	Not pestled. Boiled twenty-three hours. Per cent.	Not pestled. Boiled nine days. Per cent.	Not pestled. Boiled eight and a half days. Per cent.	Pestled. Not boiled. Per cent.
By sieves	3.36	3.24	3.63	3.49
0.25-0.05	1.21	1.11	1.91	1.29
0.05-0.01	28.27	33.04	33.61	27.02
0.01-0	56.29	48.85	54.78	52.21
Clay	4.92	3.05	1.97	10.15
Loss on ignition . . .	5.95	5.95	5.95	5.95
	100.00	95.24	101.85	100.11

It is observed that the eight to nine days boiling diminished the clay as determined by Hilgard's conventional method by from seven to eight per cent, increasing the dust by from two to three per cent, and the silt by about six per cent.

Under the microscope small, rounded, opaque, brown granules were seen in large numbers, which when pressed under the cover glass, broke up into a multitude of very fine particles.

From these experiments it would appear to be conclusively proved that too long boiling precipitates clay and thereby defeats the very object of the operation.

In these experiments the time of boiling was prolonged in order to bring out unmistakably the effects of this operation. If ebullition for eight or nine days reduces clay from ten to two per cent, increasing the 0.05-0.01 millimeter diameter grades by six per cent, it is evident that boiling for one day or a shorter time becomes a questionable treatment.

Further experiments made by boiling clay in a platinum vessel with a platinum condenser showed that this precipitation of the clay was largely if not wholly due to the salts extracted from the soil.⁸³

When the clay has once been converted into the granular condition, considerable difficulty is experienced in restoring it to the state in which it is capable of prolonged suspension in water.

Osborne sums up the results of the studies reported, as follows :

1. The Berlin-Schöne method of elutriation gives fairly correct separations with sandy soils containing little clay or matters finer than 0.01 millimeter diameter, but on soils of fine texture, as loams rich in humus and clays, it gives results which are grossly inaccurate, the error on single grades amounting to from eight to fourteen per cent.

2. In respect of rapidity, economy of time, and ease of operation, the Schöne elutriation has no advantage over the beaker method.

3. Schloesing's method on its mechanical side makes no satisfactory separations, and the chemical treatment it employs is liable to alter seriously the texture of the soil.

4. The determination of clay by a single subsidence from any conventional depth or volume of water, or for any conventional time, is not a process certain to effect even a roughly approximate separation of the finest quartz grains from true clay.

5. Boiling with water must be rejected as a treatment preliminary to mechanical analysis, because it not only abrades and reduces the coarser sediments, but may dehydrate and coagulate the true clay and thus alter essentially the texture and grain of the soil.

266. Acceleration of Sedimentation.—Attention has already been called to the acceleration of sedimentation secured by invoking the aid of centrifugal force in the pendulous motion imparted to the elutriating vessels in the Bannigsen process. It is evident that other things being equal the time of sedimentation is inversely as the magnitude of the centrifugal force from the motion that force becomes great enough to neutralize the force of

⁸³ Report Connecticut Agricultural Experiment Station, 1888 ; Part II, 156.

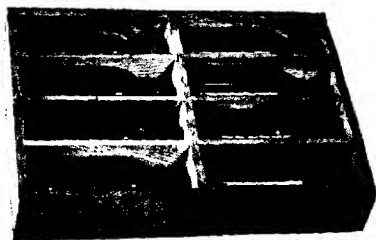


Fig. 43.—Shaker Tray Containing Bottles.

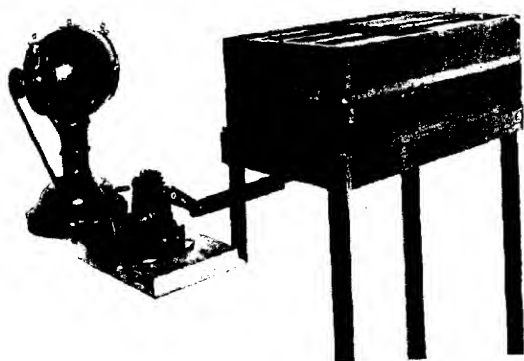


Fig. 44.—Mechanical Shaker Used in Preparing Soils for Mechanical Analysis.

gravity. By the use of a centrifuge it is therefore evident that the time of sedimentation may be greatly shortened. These principles underlie the process of centrifugal sedimentation elaborated by Briggs.⁸⁴

Preparation of Sample.—Lumpy soils are reduced by a wooden rolling pin in preference to pestling or grinding, and passed through a sieve of two millimeters mesh. Gravel and other particles not passing the sieve are weighed. The part of the fine earth passing the sieve designed for mechanical analysis (from ten to 20 grams) is shaken with water for a few hours in a shaking machine shown in Figs 43 and 44. The five-gram samples are introduced into 250 cc. cylindrical round-bottomed sterilizing bottles, each containing approximately 75 cc. of distilled water. Ten drops of strong ammonia (sp. gr. = 0.9) are added to each bottle, which is then closed with a well-fitting rubber stopper. The bottles are placed in individual compartments in trays, each tray holding eight bottles, (Fig. 43), which corresponds to the number of samples usually analyzed at a time.

The shaker illustrated in the accompanying figure (Fig. 44), consists of a platform for carrying the trays, resting upon four flexible wooden supports, to which a reciprocating motion is imparted by a crank. Each tray is provided with a pin at either end which engages with the tray above it, so that six trays may be placed upon the shaker at one time, all easily accessible. The shaker is driven by a one-sixteenth horse-power motor which is belted to a fiber worm-reducing gear, provided with a crank to which the shaker is connected. The crank is five centimeters in length, and runs at 100 revolutions per minute. If the motor used with the machine is of the series of "fan" type, it is necessary to have a regulating rheostat, which is usually provided in the base of the motor, to adjust the speed when the shaker is not fully loaded. With a shunt wound motor, running at practically constant speed, a rheostat is not necessary, providing the reducing gear has been designed to drive the shaker at the proper speed.

This form of shaker is more convenient than one in which the platform is supported from above, since the supports do not inter-

⁸⁴ Bulletin No. 24, Bureau of Soils, *The Centrifugal Method of Mechanical Soil Analysis*; Briggs, Martin and Pearce.

fers with the removal of the trays. The use of thin steel or wooden supports, set with their planes at right angles to the direction of motion avoids the necessity of guides to prevent lateral motion, while little resistance is encountered to motion in the direction parallel to the plane of the crank.

THE CENTRIFUGAL MACHINE.

The primary requisite in making a mechanical analysis by the centrifugal method is some means of securing the high velocity required to throw down the suspended soil particles. An electric motor is most suitable for this purpose, if an electric lighting circuit is available. Large direct current series motors of the desk fan type are very satisfactory. Alternating current induction motors, of the desk fan type, are not sufficiently powerful to give satisfactory results. In case an alternating current circuit is the only one available, a belt driven apparatus used in connection with an induction motor of preferably one-half horse-power capacity should be employed.

The centrifugal apparatus illustrated in Fig. 45 consists of a 110-volt, 16-inch fan motor, mounted with its shaft in a vertical position, to which is attached a spider carrying eight trunnioned frames. The distance from the center of the motor shaft to the center of the trunnion screws is ten centimeters, and the depth of the trunnioned racks is 15 centimeters. The centrifugal tubes consist of large heavy glass test tubes 18x3 centimeters, which are supported to the trunnioned racks. The aperture in the upper ring of the support is made large enough to admit the test tube readily, while the opening in the lower ring is smaller than the tube, and is faced with a felt cushion on which the tube rests. It is important that the tubes should be thoroughly annealed, otherwise breakage is apt to occur under the strain to which they are subjected in the machine. To protect the operator from such accidents, a guard surrounds the movable portion of the machine.

The motor is provided with a rheostat in its base, giving four different speeds, which enables one to start the motor slowly and bring it gradually up to full speed. The machine when loaded and running at full speed requires about one minute to stop after the circuit is opened. To avoid this delay, the motor is provided

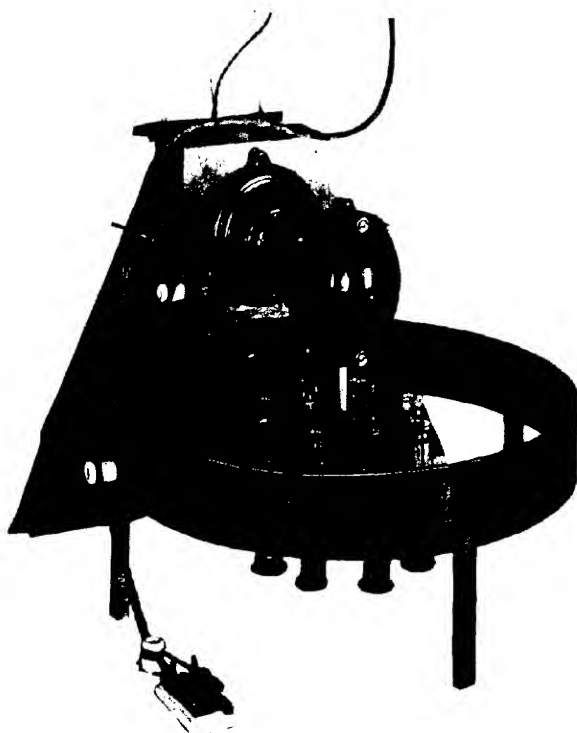


Fig. 45. Centrifugal Machine Used in Mechanical Analysis of Soils.

with a reversing switch, by means of which the direction of the current through the armature may be reversed, and the motor brought quickly to rest. Before stopping the machine in this way, the rheostat should be set at the first speed, and then slowly moved to the second or third speed, in order that the motor may not be subjected to too great mechanical and electrical strains in the reversing process. The microscopic method of examining the deposited silt is the same as in the other methods of silt separation.

267. Centrifugal Elutriator.—A combination of the principles of silt separation by a current of water and by centrifugal force is illustrated by the process of Yoder.⁸⁵ The object of the method is to be able to use a higher velocity of current for the separation of any one of the group particles and thus to accelerate the manipulation. The apparatus is shown in Figs. 46 and 47.

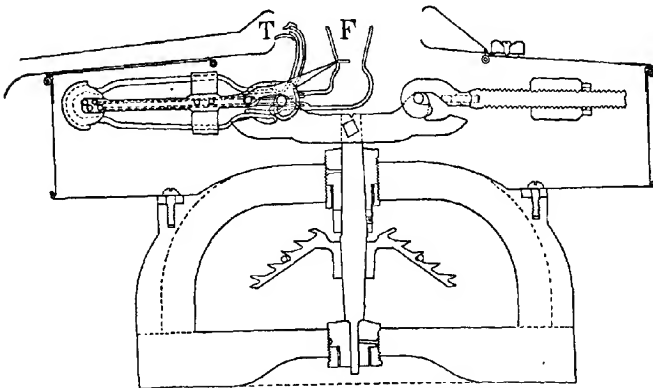


Fig. 45. Yoder's Centrifugal Elutriator ; vertical section.

Figure 47 shows the elutriator flush in longitudinal section, while Fig. 46 gives the details of construction.

The bottle is so designed that in the portion in which the separation is effected the velocity of the water column and the centrifugal force decrease in the same ratio, as the axis of the machine

⁸⁵ Bulletin 89, Utah Experiment Station. Bulletin 24, Bureau of Soils : 30 et seq.

is approached. A suspended particle is consequently subjected to a uniform force while in this portion of the bottle.

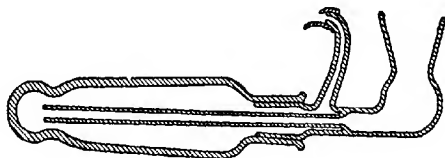


Fig. 47. Centrifugal Elutriator Bottle: longitudinal section.

It is not found practicable to stir the sediment in the bottom of the bottle by the inflowing current of water, consequently the material to be separated, suspended in a stream of water, is gradually introduced into the machine. The apparatus is used only in separating particles less than 0.03 mm. in diameter, this finer material being first separated from the rest of the sample by the beaker method. The water containing this fine material in suspension is run at a uniform rate through the machine, being introduced into the bottle through the funnel *F*, the axis of which coincides with the axis of the centrifugal machine, and coming out at the opening *T*, where it is caught by the spray collector shown in the upper part of figure. The size of the particles which pass out of the machine suspended in the water depends both upon the velocity of the stream of water and upon the speed of the machine.

A uniform flow of water containing the suspended material is secured in the following manner: The water containing the suspended material is placed in a funnel closed at the top, from which it flows into the machine as fast as air is admitted into the funnel. The air comes from a large closed bottle serving as an air chamber, into which the water flows from a mariotte apparatus, placed above, through a graduated valve that can be regulated at will.

The machine is first operated at such a speed that all particles larger than the superior limit of the group containing the finest material are precipitated to the bottom of the elutriator bottle. During this process some of the finest material is also carried down with some of the largest particles. The machine is then

stopped, the material in the bottom of the centrifugal bottle again suspended in water, and the operation repeated with the machine running at such a speed that the soil grains belonging to the group of coarsest particles will alone be precipitated. This process is continued until a sharp separation is obtained. The same procedure is followed for the other separations.

This method of separation has not been subjected to trial by the author of this treatise. It appears to introduce into the methods of silt separation a somewhat complicated piece of apparatus, novel in structure, but apparently of no great practical benefit.

268. Method of Sjollesma.—This method is based on the principle of separating by centrifugal force the fine particles of the soil suspended in a thoulet solution of 2.51 specific gravity.⁸⁶ The inventor has improved his original method in several respects. The thoulet solution (described further on) has been replaced by a mixture of bromoform and chloroform of the same specific gravity.⁸⁷

The centrifuge employed is similar to those used in the analysis of urine. By this device the clay and sand are separated, the former, at the end of the operation, being found on top, and the latter at the bottom of the liquid. It is evident that flocculated particles of clay attached to the heavier sand particles would be found at the bottom of the liquid, and therefore the separation could only be theoretically accomplished in a condition where the particles both of clay and sand are perfectly segregated.

The process is conducted as follows:⁸⁸

Soil which contains much sand or undecomposed mineral matter is rubbed in a mortar with water. The liquid after standing a short time is poured off and this treatment is repeated several times. Care is taken not to break up the grains during the pestling. The portions poured off are evaporated nearly to dryness on a water-bath. The residue is still further dried in a desiccator, placed in a mixture of bromoform and chloroform of a specific gravity of 2.5 and centrifuged for two or three minutes. The greater part of the sand is separated by this treatment. After the

⁸⁶ *Chemiker Zeitung* 1895, 19 : 2080.

⁸⁷ *Proceedings of the 4th Congress of Agriculture, Paris, 1900*, 2 : 132.

⁸⁸ *Die landwirtschaftlichen Versuchs Stationen*, 1900, 58 : 71.

operation the vessels containing the mixture are left at rest for a short time during which suspended particles go to the bottom or come to the top.

The separating fluid carrying the lighter particles is thrown upon a filter which retains the colloidal substances which are subsequently washed with ether, dried and removed from the filter. The colloid mass is purified by moistening with water, rubbing in a mortar as before, the moisture nearly driven off and dried as before.

It is again submitted to centrifugal action, but with such addition of chloroform to the separating liquid as to reduce the specific gravity to about 2.32, which is very nearly that of the colloid substance itself. If the microscope still reveals particles of sand in the colloid the treatment above outlined is to be repeated.

269. Methods of Measuring the Diameter of Silt Groups.—During the progress of separation of the groups of silt particles the size of the average particle is determined from time to time by the microscope. A drop of the water in which the particle is suspended for the time being is removed to the stage of the microscope by sucking it into a small glass tube. Attention should be paid to the desirability of getting the sample from near the center of the body of the liquid in which the particles are suspended.

After placing the cover glass over the drop of water carrying the particles the slide is brought into the field of vision and the diameters of the best formed fragments determined with the micrometer. A number should be measured each time and the average diameter computed. When this average falls very near the mean theoretical size of the group the separation may be regarded as ended. Distorted or unusual forms should be omitted in the measurement and these should be regarded as having the same hydraulic value as the spheroid or regular forms measured. Further details respecting the microscopical examination will be given in another place.

270. Methods of Tabulation.—In the United States the chief methods of tabulation are those proposed by Hilgard, Whitney and Osborne, which have already been illustrated. Hopkins has

proposed a method of tabulation of results based upon the relation of the $\sqrt[3]{10}$ times that of the inferior group.⁸⁹

The numerical value of the $\sqrt[3]{10}$ is nearly 3.2 and this number is used as the multiplier for each group above the smallest, excluding clay. In Hopkin's scheme the smallest group of particles has a diameter of .001 millimeter or less.

A comparison of the different methods of tabulation is given in the following table:⁹⁰

SYSTEMS OF GROUPING EMPLOYED IN MECHANICAL ANALYSIS.

Number of group.	Hilgard. mm.	Osborne mm.	Bureau of soils. mm.	Hopkins. mm.
(1)	3.0	3.0	2.0	1.0
(2)	1.0	1.0	1.0	0.32
(3)	0.5	0.5	0.5	0.1
(4)	0.3	0.25	0.25	0.032
(5)	0.16	0.05	0.1	0.01
(6)	0.12	0.01	0.05	0.0032
(7)	0.072	(?)	0.005	0.001
(8)	0.047	....	....	....
(9)	0.036	....	....	....
(10)	0.025	....	....	....
(11)	0.016	....	....	....
(12)	0.010	....	....	....
(13)	(?)	....	....	....

There is little practical advantage in increasing the number of groups, however important it may be in a detailed study of a soil. The chief agronomic questions relating to the composition of a soil are answered by the determination of the parts that pass a 2, 1 and .5 millimeter sieve and by dividing the fine earth from the last mentioned sieve into clay remaining in suspension for 24 hours and into three or four intermediate groups.

271. General Conclusions.—The methods of Hilgard and Osborne have been given in detail and largely in the descriptive language used by the authors. The other methods of elutriation in use in other countries have also been described. For practical use the methods of Hilgard and Osborne are to be preferred to all others. For simplicity and speed the Osborne method has the preference over the Hilgard. For rigid control of the work the

⁸⁹ Bulletin 56, Bureau of Chemistry : 64.

⁹⁰ Bulletin 24, Bureau of Soils : 33.

Hilgard method leaves little to be desired. The effect of long boiling on clay pointed out by Osborne would suggest that the boiling process preliminary to the Hilgard method be made as short as possible. It would seem that the churn attrition in the Hilgard method might well be regarded as a substitute for the soft pestling of the Osborne process, and any prolonged boiling in the former method might be safely omitted. When carefully carried out, the results of the Hilgard and Osborne method are fairly comparable.

272. Distribution of Soil Ingredients.—The distribution of the soil ingredients in the sediments obtained in silt analysis is illustrated in the following table:⁹¹

Hydraulic value . . . Clay	< 0.25 mm.		0.25 mm.		0.5 mm.		1.0 mm.		Other sediments	Total in sediments	Original soil.
Per cent. in soil	21.64		23.56		12.54		13.67		13.11		
	A	B	A	B	A	B	A	B	A	B	
Insoluble residue	15.66	4.35	73.17	17.29	87.95	11.03	94.13	12.72	96.52	12.74	13.76
Soluble silica	33.10	7.17	9.95	2.34	4.27	0.53	2.35	0.32	..	..	10.36
Potash	1.47	0.32	0.53	0.12	0.29	0.04	0.12	0.01	..	..	0.49
Soda	1.70	..	0.24	0.06	0.28	0.04	0.21	0.02	..	..	0.12
Lime	0.09	0.03	0.13	0.03	0.18	0.02	0.09	0.01	..	..	0.09
Magnesia	1.33	0.29	0.46	0.11	0.26	0.03	0.10	0.01	..	..	0.44
Manganese	0.50	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.36	..	0.06
Ferric oxid	18.76	4.06	4.76	1.11	2.34	0.29	1.03	0.14	..	..	5.60
Alumina	18.19	3.97	4.32	1.04	2.64	0.33	1.21	0.17	..	..	5.51
Phosphoric acid	0.18	0.04	0.11	0.02	0.03	0.00	0.02	0.00	..	..	0.05
Sulfuric acid	0.06	0.01	0.02	0.01	0.03	0.00	0.03	0.00	..	..	0.02
Volatile matter	9.00	1.33	5.61	1.43	1.72	0.23	0.92	0.29	..	..	3.04
Total	100.14	21.64	99.30	23.56	100.00	12.54	100.21	13.67	..	13.10	98.28
Total soluble matter	75.18	..	20.52	..	10.32	..	5.16	..	..	..	..
Total soluble bases	41.84	..	10.44	..	5.99	..	2.76	..	..	..	..
Soluble silica in crude substance	0.38	0.01	..	..	..	..	..	..	..	..	0.19

A. Calculated on the amount of sediment.

B. Calculated on the amount of soil.

The separation into soluble and insoluble constituents was effected in the above analysis by five days hot digestion in hydrochloric acid of 1.115 specific gravity.

It is seen from the above analyses that the clay is by far the richest in mineral constituents of all the ingredients separated in silt analysis, the amount in the clay being more than twice that of all the others combined. Its volatile matters are also the largest. The large amount of soda, however, is probably in part due to

⁹¹ Loughridge, Proceedings American Association for the Advancement of Science, 22nd meeting (Portland, Me.), 1873; 81.

the sodium chlorid used in the precipitation of the diffused clay. The following points in regard to the distribution of the different ingredients are instructive:

1. The iron and alumina exist in almost identical relative proportions in each sediment, making it probable that they are in some way definitely correlated.

2. Potash and magnesia also exist in almost the same quantities, and their ratio to each other in all the sediments being almost constant seems to indicate that they occur combined, perhaps in some zeolitic silicate which may be a source of supply to plants.

3. Manganese exists only in the clay, a mere trace being found in the next sediment.

4. The lime appears to have disappeared in the clay, having probably been largely dissolved in the form of carbonate by the large quantity of water used in elutriation. Its increase in the coarser portions may be owing to its existence in a crystallized form not so readily soluble.

5. In a summary of the ingredients, it is seen that there is a loss in potash, magnesia and lime in the sediments as compared with the original soil; and this loss is doubtless due to the solution of these bodies in the water of elutriation.

A noteworthy fact shown in this table is the rapid decrease of acid-soluble matter in the coarser sediments; even what is dissolved from so fine a sediment as 1.0 millimeter hydraulic value, equal to a diameter of 0.04 millimeter, is in this case a negligible quantity. This suggests forcibly the inutility of introducing into chemical soil analysis, grains of as large a size as will pass a sieve of one millimeter aperture. The hydraulic value of these grains would be somewhat between 150 and 200 millimeters per second. While the exact results of the above analysis may not be applicable to all soils, yet the range is so wide that the systematic exclusion from chemical analysis of inert materials, by means of preliminary mechanical separation, seems likely to lead to important improvements in the interpretation of the results.

273. Percentage of Silt Classes in Different Soils.—The adaptation of a soil to different crops depends largely on the sizes of the particles composing it and consequently on the relative percentages of the silt classes.

The following table gives the mechanical analysis of some markedly different types of subsoils:⁹²

Diameter, millimeters.	Conventional names.	Truck and small fruit.		Tobacco.	Wheat.	Grass and Wheat.	Lime- stone.
		1.	2.				
2-1	Fine gravel ..	0.49	0.04	1.53	0.00	0.00	1.34
1-0.5	Coarse sand ..	4.96	1.97	5.67	0.40	0.23	0.33
0.5-0.25	Medium sand.	40.19	28.64	13.25	0.57	1.29	1.08
0.25-0.1	Fine sand	27.59	39.68	8.39	22.64	4.03	1.02
0.1-0.05	Very fine sand	12.10	11.43	14.95	30.55	11.57	6.94
0.05-0.01	Silt	7.74	4.95	28.86	13.98	38.97	29.05
0.01-0.005	Fine silt	2.23	2.02	7.84	4.08	8.84	11.03
0.005-0.0001	Clay	4.40	8.79	14.55	21.98	32.70	43.44
		99.70	97.52	95.04	94.20	97.63	94.23
Org. matter, water and loss.		0.30	2.48	4.96	5.80	2.37	5.77

274. **Description of the Soils.**—Number one represents the very early truck lands of Southern Maryland. It is a light yellow sand, belonging to the Columbia terrace formation. Under an intense system of cultivation and heavy manuring with organic matter, good crops of garden vegetables are produced which mature very early, at least ten days or two weeks before the crops from any other part of the state. Under the prevailing meteorological and cultural conditions this soil maintains about five or six per cent of moisture, while a heavier wheat and grass soil maintains from 12 to 20 per cent. The truck soil is so loose and open in texture that the rain-fall passes through it very readily, and it is undoubtedly partly owing to this drier soil that the plant is forced to the early maturity which secures it from competition from other parts of the State and insures a good market price.

Number two represents the later truck and fruit lands of southern Maryland. These lands contain rather more clay than those just described; they are somewhat heavier and closer in texture, and are rather more retentive of moisture. This land gives a larger yield per acre than the one just described, and in every way crops make a more vigorous growth and development, but the crop is about a week or ten days later in maturing, and for this reason it brings a lower price in the market. It is much bet-

⁹² Whitney, Bulletin 4, Weather Bureau : 60, 64, 65, 69, 71, 73.

ter land than number one for small fruit and peaches. These lands are altogether too light in texture for the profitable production of wheat, and it would cost altogether too much to improve them so that even a moderate yield of wheat could be obtained.

Number three is a tobacco soil of southern Maryland. The finest tobacco lands of this locality come between the truck and wheat lands in texture, and contain from ten to 20 per cent of clay. The lighter the texture of the soil and the less clay it contains, the less tobacco it will yield per acre, but the finer the texture of the leaf. The tobacco yields more per acre on the heavier wheat soils, but the leaf is coarse and sappy and cures green and does not take on color. It brings a very low price in the market and does not pay for cultivation. The crop on the lighter lands is of much finer quality; there is a smaller yield per acre but the leaf takes on a fine color in curing, and brings a much better price per pound. Wheat is commonly raised on these tobacco lands to get the after advantage of the high manuring, and because the rotation is better for the land than where tobacco is grown continuously on the same soil. The finest tobacco lands are, however, too light in texture for the profitable production of wheat. These lands belong to the neocene formation.

Number four is a type of the wheat soils of southern Maryland. These soils represent about the lightest texture upon which wheat can be economically produced under the climatic conditions which there prevail. They contain from 18 to 25 per cent of clay, and are much more retentive of moisture than the best tobacco lands. This type is about the limit of profitable wheat production. These soils will maintain about 12 per cent of water during the dry season. Garden truck is so late in maturing on these lands that there is often a glut in the market when the crop matures, and the crops often do not pay the cost of transportation. The lands are too light in texture for a permanent grass sod. They belong to the neocene formation.

Number five represents the heavier wheat soils of southern Maryland, belonging probably to a different period of the neocene formation and containing about thirty per cent of clay. This soil is much more retentive of moisture and produces very much larger crops of wheat than the last sample. It is strong enough

and sufficiently retentive of moisture to make good grass lands. It is too close in texture and too retentive of moisture for the production of a high grade of tobacco, or to be profitable for market vegetables.

Number six is from a heavy limestone soil of lower Helderberg formation. It is a strong and fertile wheat and grass land.

275. Interpretation of Silt Analysis.—There is evidently some connection between the size of the soil particles and the character of the crop best suited to a given mechanical type of soil. Early vegetables are hastened to maturity either in light, sandy soils or on the black vegetable soil of pond bottoms which has no relation whatever to the composition of the essentially mineral soils first described. Wheat and grass do not thrive well on sandy soils and a certain quantity of clay seems very helpful to such crops. But 'clay' is not merely particles of very small size, but rather such particles consisting essentially of silicates, especially of alumina. The only relation which the size of soil particles has to the total or available fertility is connected with the relation of the particles to the root system of the plant. Fine quartz sand, no matter how divided its particles might be, would not support vegetable life. It has been shown by studies in the yield of beets that soil fertility has no direct relation to mechanical structure, save as indicated above.⁹³ The chemical constitution of the fine particles therefore must be known before any definite idea of fertility can be acquired.

276. Number of Particles in a Given Weight of Soil.—The approximate number of particles in the soil can be calculated from the results of the mechanical analysis by the following formula:⁹⁴

$$\frac{a}{\frac{\pi(d)^3 \omega}{.6}} \div A.$$

Where a is the weight of each group of particles, d the mean diameter of the particles in the several groups in centimeters, ω is the specific gravity of the soil, and A is the total weight of soil. for the specific gravity of ordinary soils, the constant 2.65 may be used.

⁹³ Bulletin 78, Bureau of Chemistry : 48.

⁹⁴ Whitney, Bulletin No. 4, Weather Bureau : 33.

The diameter d is taken as the means for the extreme diameters taken for any group, for instance, for the silt this would be 0.003 centimeter, which is assumed to be the diameter of the particles in that group. This formula can only give approximate values, as the number of separations in a silt analysis must necessarily be small, amounting usually to not more than eight or ten grades, on account of the time and labor required for closer separations. There is relatively rather a wide range in the diameters of grains within any one of these grades, and absolute values could not be expected without a vast number of separations, so that all the grains in each group would be almost exactly of the same size.

The clay group has relatively the widest limits, which is unfortunate, as this is the most important of all the groups on account of the exceedingly small size of the particles. The figure 0.0001 millimeter is taken as the lowest limit of the diameter of the clay particles. These particles have been heretofore assumed to be ultra-microscopic, but by the use of a microscope of high power with oil-immersion objective and staining fluids, it has been possible to define the clay particles in a turbid liquid which has stood so long as to be only faintly opalescent.

Pending more exact measurements, the figure 0.00255 millimeter has been used as the diameter of the average sized particle in the clay group.

277. Mineralogical Examination of the Particles of Soil Obtained by Mechanical Analysis.—The principal object of the mechanical analysis of soils as has already been set forth is the separation of the soil into portions, the particles of which have nearly the same specific gravity and hydraulic value. It is evident without illustration that particles of the same hydraulic value do not necessarily have the same size. The rate of flow of a liquid carrying certain definite particles does not imply that these particles are of the same dimensions. Of two particles of the same size and shape, that one which has the lower specific gravity, will be carried off at the lower rate of flow. At the end of the operation, therefore, the several portions of the soil obtained will be found composed of particles of sizes varying within certain limits, and of these particles the larger ones will tend to be composed of minerals of lower specific gravity, and

*the smaller ones of minerals of higher specific gravity. Of the same mineral substance, the particles which are most irregular, exposing for a given weight the largest surface will be found to pass over at a lower velocity than those of a more nearly spherical shape. The same law holds good for particles falling through a liquid at rest, i. e., the heavier and more spherical particles, weight for weight, will sooner reach the bottom of the containing vessel. To complete the value of a mechanical analysis, it becomes necessary to submit the several portions of soil obtained not only to a chemical but also to a mineralogical examination. Only the outlines of the methods of examining silt separates for mineral constituents can be given here and special works in petrography must be consulted for greater details.*⁹⁵

It is evident that the methods of separation and examination from a mineralogical point of view about to be described can only be applied to silts of the largest size. The finer silts can not be separated into portions of different specific gravities by separating liquids of varying densities on account of the slowness with which they subside, thus tending to adhere to the sides of the separating vessels and to form floccules which are not all composed of the same kind of mineral particles. While, therefore, these processes are more appropriately described in connection with the silts obtained by hydraulic elutriation, they can be applied with greater success to the fine particles passing the different sieves used in the preparation of the soil for analysis or to the finely pulverized soil as a whole.

The minerals which have contributed to soil formation, moreover, are better preserved in the larger silt particles and therefore more easily identified. While the desirability of securing like determinations in the finer silts is not to be denied, in the present state of the art the analyst must be content with the examination of the larger particles.

278. Methods of Investigation.—The chief points to be observed in the examination of the fine particles of soil are the following:

⁹⁵ Anleitung zur mineralogischen Bodenanalyse, Franz Steinreide Leipzig, published by William Engelmann, and Microscopical Physiography of Rockmaking minerals, H. Rosenbusch, Translated by J. P. Iddings, John Wiley & Sons, New York.

(1) the size and shape of the particles; (2) measurement of crystal angles; (3) separation into classes of approximately the same specific gravity; (4) separation by means of the magnet; (5) determination of color and transparency; (6) determination of refractive index; (7) examination with polarized light; (8) examination after coloring; (9) chemical separation. For many of the optical studies above noted, it is first necessary to prepare thin laminæ of the mineral particles and properly mount them for examination. For the purposes of this manual only those processes will be described which are essentially connected with a proper understanding of the nature of the soil particles. For the more elaborate methods of research the analyst will consult standard works on mineralogy and petrography.

279. Microscopical Examination.—The direct examination of the silt particles with the microscope should attend the progress of separation. Unless the particles obtained have the same general appearance, the separation is not properly carried on. Especially is the microscope useful to determine if the value of the silt separation is impaired by flocculation. Unless flocculation be practically prevented during the separation of the finest particles, many of these will be left as aggregates to be brought over subsequently with particles of far different properties. No special directions are necessary in the use of the microscope. The silt particles are removed with a few drops of water by means of a pipette, a drop of the liquid with the suspended particles is placed on the glass, covered and examined with a convenient magnification. A micrometer scale should be employed in order that the approximate sizes of the particles may be determined. A *camera lucida* may also be conveniently used for the purpose of delineating the form of particles of peculiar interest.

280. Microscope.—Any good microscope furnished with polarizing apparatus may be used for the examination of the silt particles and sections. For directions in manipulating microscopes the reader is referred to works on that subject. A special form of microscope for petrographic work is shown in Fig. 48. The base, upright pillars and arm are made of japanned iron. The stage is made in two forms, first, plain revolving, having silvered grad-

uations at right angles and second, a mechanical stage with silvered graduations on the edge with vernier and graduations for the rectangular movements. The mirror bar is adjustable and graduated and the mirror is of large size, plane and concave. The

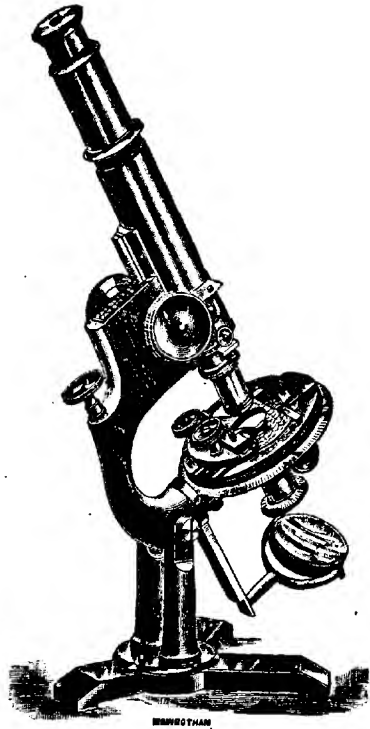


Fig. 48. Microscope for Silt Examination.

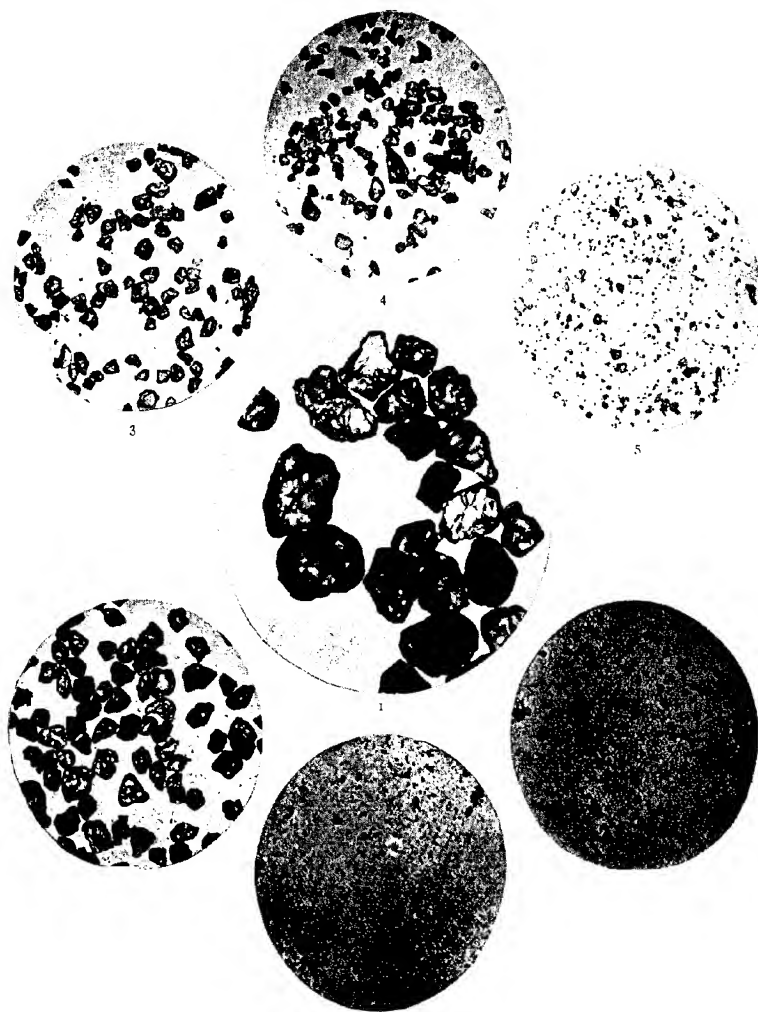
double chambered box in the main tube carries the upper nicol prism (analyzer). The lower nicol prism (polarizer) is mounted in a cylindrical box beneath the stage to which it is held by a swinging arm. It is adjustable also up or down and is provided with a compound lens for securing converged polarized light. In

revolving the prism a distinct click shows the position of the crossed nicols.

The latest form of microscope used in the Bureau of Chemistry for this work is in addition to the usual attachments provided with a revolving analyzer for the detection of very low doubly refracting minerals, and a Schwarzmans scale for the measurement of optical axial angles. Another important accessory is a detachable-screw micrometer movable in the focal plane of the ocular by means of a drum screw which with the most powerful objective lens records a drum interval of 0.00004 mm.⁹⁰

281. Form and Dimensions of the Particles.—In order to study the contour of the fine silt particles, it is well to suspend them in a liquid whose refractive index is markedly lower than that of the particles themselves, and for this purpose pure water is commonly used. Care must be taken that not too many particles are found in the drop of water which is to be placed on the object holder and protected with a thin, even glass. The tendency to flocculation in these fine particles will make the study of their form difficult if they are allowed to come too close together. The size of the particles, or linear diameter, is to be determined by means of an eye-micrometer. This consists of a glass plate on which a millimeter scale is engraved with a diamond, or photographed. The millimeter scale is the one usually employed, each millimeter being divided into tenths. On microscopes designed especially for petrographic work the micrometer is fastened to the eyepiece, and so adjusted as to read from left to right, or at right angles thereto. Sometimes an eyepiece-micrometer has two scales at right angles so that dimensions may be read in two directions without change. With an eyepiece-micrometer, not the dimensions of the object, but those of its magnified image are read, and the degree of magnification being known, the actual size of the object is easily calculated. The actual measurements may also be obtained by placing in the field of vision, a stage-micrometer and determining directly, the relation between that and the eyepiece-scale. If, for example, the stage-micrometer is ruled to 0.01 millimeter, and the eye-micrometer to 0.1 millimeter, and one

⁹⁰ Bulletin 79, Bureau of Chemistry : 39.



7
FIGURE 49. PHOTOMICROGRAPHS OF SILT PARTICLES.

No.	Diameter in mm.	Name.	Magnification, Diameters.
1	1.0 — 0.5	coarse sand	× 10
2	0.5 — 0.25	medium sand	× 10
3	0.25 — 0.1	fine sand	× 10
4	0.1 — 0.05	very fine sand	× 30
5	0.05 — 0.01	silt	× 30
6	0.01 — 0.005	fine silt	× 150
7	0.005 — 0.0001	clay	× 150

283. Measurement of Crystal Angles.—The fine silt particles rarely retain sufficient crystalline shape to permit of the measurement of angles and the determination of crystalline form thereby. The rolling and attrition to which the silt particles have been subjected have, in most cases, given to the fragments rounded or irregular forms which render, even in the largest silts, the measurement of angles impossible. For the methods of mounting minute crystals and the measurement of microscopic angles, the analyst is referred to standard works on mineralogy and petrography.

284. Determination of the Refractive Index.—For a study of the theory of refraction, works on optics should be consulted. The general principles of this phenomenon which concern the determination of the refractive power of fine earth particles are as follows: if a transparent solid particle is observed in the microscope imbedded in a medium of approximately the same refractive power and color, its outlines will not be clearly defined, but the imbedded particle will show in all of its extent the highest possible translucency. If, therefore, the form or perimeter of the particle is to be studied with as much definiteness as possible, it should be held in a medium differing as widely from it as possible in refractive power. For minerals, water is usually the best immersion material. On the other hand, when the internal structure of the particles is the object of the examination, it should be imbedded in oil, resin (Canada balsam), etc., or in some of the liquids mentioned below.

If particles of different refractive powers and the same character of surface be studied in the same medium, they will not all appear equally smooth on the field of the microscope. Some of the surfaces will seem smooth and even, others will appear rough and wrinkled. Those particles whose refractive index is equal to or less than that of the liquid appear smooth, because all the emergent light therefrom can pass at once into the environing medium. On the other hand, the surfaces of those particles which have a higher refractive power than the medium will appear roughened, because, on account of the unavoidable irregularities on the surface, many of the emergent rays of light must strike at the critical

angle and so suffer total reflection, and consequently those portions of the surface will be less illuminated, producing the phenomenon of apparent roughness above noted. In the case of any given particle, liquids of increasing refractive power can be successively applied until the change in the appearance of the surface of the particle is noticed. The refractive index of the liquid being known, that of the particle is in this way approximately to be determined.

The following liquids, having the indexes mentioned, are commonly employed:

Substance.	Refractive index.
Water	1.333
Alcohol	1.365
Glycerol	1.460
Olive oil	1.470
Canada balsam	1.540
Oil of cinnamon	1.580
Oil of bitter almonds	1.600
Oil of Cassia	1.606
Concentrated solution of potassium and mercuric iodid ..	1.733
Concentrated solution of barium and mercuric iodid	1.775

The solution of potassium and mercuric iodid may also be used for all refractive indexes from 1.733 to 1.334 by proper dilution with water.

The mineral particle may also be imbedded in Canada balsam and over it a drop of a liquid of known refractive power placed. By a few trials one of the liquids will be found having practically the refractive index of the particle under examination.

285. Examination with Polarized Light.—The internal structure of a mineral particle can often be determined by its deportment with polarized light. The theory of polarization is fully set forth in works on optics and will not be discussed here. The principle on which the utility of polarized light in the examination of soil particles rests is found in the information it may give in respect of crystalline structure. The structure of mineral particles which make up the bulk of an ordinary soil is, as a rule, so thoroughly disintegrated that all trace of its original form is lost.

Some particles may exist, however, in which there is no determinable element of shape and which yet possess an internal crystalline structure which the microscope with polarized light may be able to reveal.

An important feature of the microscopical examination of a mineral section is the determination of the relative abundance of the mineral components. To this end an ordinary fixed eyepiece having a square field is divided into 100 quadratic areas. With the aid of this device each square of which is the one-hundredth of the whole field the relative abundance of the minerals occupying the field can be determined with a great degree of accuracy, and entered on appropriate blanks.⁹⁸

286. Staining Silt Particles.—The finer silts and clays before microscopic examination should be colored or stained. The methods used in staining bacteria may be employed for the clay particles.

Evaporation to dryness with a solution of magenta will often impart a color to the clay particles which is not removed by subsequent suspension in water. The harder and larger silt particles are not easily stained, especially if they be firm and undecomposed. On the other hand, if the particles be broken and seamed, and well decomposed, the stain will be taken up and held firmly in the capillary fissures. Valuable indications are thus obtained respecting the nature of the silt particles. Particles of mica, chlorite and talc are easily distinguished in this way from the firmer and less decomposed quartz grains.

Strictly-speaking, only the colloid or pectoid particles which have lost all traces of crystalline structure are sensitive to coloring agents. In a mixture of such particles with undecomposed mineral aggregates only the former will take the color; for example, methyl blue. In this way the use of a stain may indicate to a certain extent the physical state of the particles under examination.

The staining of the particles after ignition and treatment with acids gives better results than the direct treatment. Particles of carbonate which are stained with difficulty before ignition take

⁹⁸ Bulletin 79, Bureau of Chemistry : 39 and 58 et seq.

the stain easily afterwards on account of the decomposition produced by the loss of carbon dioxide. This is the case also with particles containing water of composition or crystallization.

287. Cleavage of Soil Particles.—A microscopic examination of the cleavage of soil particles may be useful in determining their mineral origin. The course followed by cleavage lines and their mutual position is dependent on the direction in which the separation of the mineral fragments takes place. The character of the microscopic fragments produced by crushing a soil particle is determined primarily by the system of crystallization to which it belongs. Perhaps the most distinguishing cleavage marks in soil particles will be found in fragments of mica and orthoclase. These characteristic forms are shown in Figs. 50 and 51. The first (Fig. 50) shows the pinacoidal cleavage in a fragment of mica. Fig. 51 illustrates the appearance of the cleavage lines in a fragment of orthoclase. Figs. 52 and 53 show the characteristic cleavage lines in fragments of epidote and titanite.⁹⁹

288. Microchemical Examination of Silt.—The methods of quantitative chemical examination of silts will be given in another part of this manual. Certain qualitative and microchemical tests, however, are useful in identifying silt particles. For instance, any soluble iron mineral will be detected, even in minute quantity, by the blue coloration of the solution produced by the addition of potassium ferrocyanid. Manganese will be revealed by fusion with soda and saltpeter on platinum foil, in the oxidizing flame, producing the well-known green coloration due to the sodium manganate formed.

More valuable indications of the character of the fragments examined are obtained by microchemical processes. The best method of decomposing the silt particles for this purpose is by treatment with hydrofluosilicic acid. When the particles are composed of silicates, pure hydrofluoric acid is to be preferred.

The method of treatment is essentially that of Boricky.¹

⁹⁹ Rosenbusch, *Mikroskopische Physiographie*, Stuttgart, 3rd Edition, 1892 : Plate x.

¹ Rosenbusch, *Mikroskopische Physiographie* : 259. Boricky, *Elemente einer neuen chemisch-mikroskopischen Mineral- und Gestein-analyse*, Prag, 1877.



FIGURE 50.

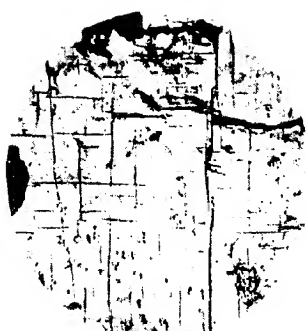


FIGURE 51.



FIGURE 52.



FIGURE 53.

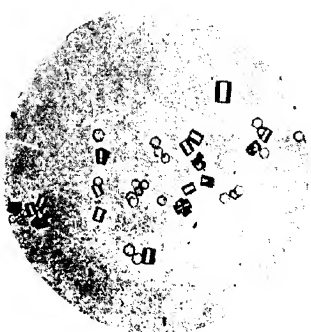


FIGURE 54.

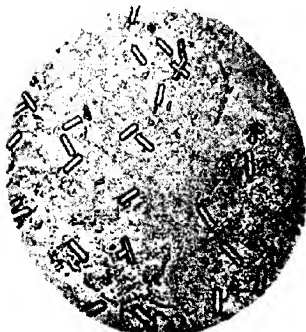


FIGURE 55.

Figures 50-55, show examples of the various degrees of perfection and relative positions of cleavage lines.

Figure 50. Illustrates pinacoidal cleavage in mica from granite. Magnified thirty diameters.

Figure 51. A cleavage of orthoclase from augite syenite magnified twenty-seven diameters.

Figure 52. Cleavage of epidote magnified sixty diameters.

Figure 53. Cleavage of titanite magnified seventy-five diameters.

Figure 54. Sodium fluosilicate crystals magnified seventy-two diameters.

Figure 55. The same with aluminum fluosilicate magnified twenty-seven diameters.

The slide used is protected by a film of canada balsam, and a few of the silt particles are placed thereon, and fixed in place by slightly warming the balsam. Each particle is then treated with a drop of hydrofluosilicic acid, care being taken not to let the drops flow together. The acid must be pure, leaving no residue on evaporation. The acid should be prepared by the analyst from a mixture of barium fluorid, sulfuric acid and quartz powder, or the commercial article should be purified by distillation before using. The acid should be kept in ceresin or gutta-percha bottles and must be applied with a ceresin or gutta-percha rod. Each particle should be as completely dissolved as possible by the acid, and the rate of solution may be hastened by gentle warming, provided the heat is not great enough to remove the balsam and allow the acid to attack the glass. The univalent and bivalent bases present in the silt particles crystallize on drying as flousilicates. In case of a too rapid crystallization, the mass may be dissolved in a drop of water or of very dilute hydrofluosilicic acid, and allowed to evaporate more slowly. Some fragments need more than one treatment with acid to secure complete solution, and particles of mica may even resist repeated applications. In such a case the decomposition may be made in a platinum crucible with hydrofluoric acid, adding afterwards an excess of hydrofluosilicic acid and evaporating to dryness. The crystals may then be dissolved in a little water and a drop of the solution allowed to crystallize on the slide.

289. Special Reactions.—The number of microchemical reactions is very great, but there will be given here only some of the more important for silt identification.²

Sodium.—Sodium mineral fragments dissolved in hydrofluosilicic acid and dried give the combinations shown in Fig. 54. With sodium and aluminum the forms shown in Figs. 55 and 56 are obtained.³ With an increasing amount of lime in the mineral, the crystals tend to become longer. For microscopic work it is not advisable to try to produce the tetrahedral crystals of the double uranium sodium acetate because the commercial uranium

² Rosenbusch, *Mikroskopische Physiographie* : 262 *et seq.*

³ Figs. 54 to 57 inclusive are reproduced from the plates in Rosenbusch's work, cited above.

acetate often contains sodium and even the pure article will often take up sodium from the bottles.

Potassium.—Fragments containing potash give isotropic clear cubes, or octahedra of low refracting power, or combinations of these forms with each other and with rhombic dodecahedra. These crystals have the composition K_2SiF_6 . Their forms are shown in Figs. 57 and 58. In case much sodium be present, the first crystals obtained may be strongly double-refractive rhombohedra, but on dissolving in water and allowing to recrystallize, the normal forms will be obtained. If the crystals be dissolved in hydrochloric or sulfuric acids, and treated with platinum chlorid, the characteristic yellow octahedral crystals of K_2PtCl_6 will be obtained. Ammonium and cesium compounds also give this reaction.

Lithium.—When fragments containing lithium are treated with the solvent mentioned, monoclinic crystals are produced on drying. These crystals dissolved in sulfuric acid and freed from calcium sulfate by treatment with potassium carbonate give aggregates of lithium carbonate resembling a snowflake. At a high temperature lithium solutions treated with sodium phosphate give spindle-shaped crystals of lithium phosphate. The double lithium aluminum silicofluorid is shown in Fig. 59. The ease with which traces of lithium may be detected by the spectroscope renders unnecessary any further description of its microchemical reactions.

Calcium.—Nearly all mineral particles, save quartz grains, contain calcium. When these particles are dissolved by treatment with hydrofluosilicic acid, they form on drying hydrated monoclinic crystals of calcium silico-fluorid ($CaSiF_6 + 2H_2O$). These crystals assume many forms, some of which are shown in Figs. 60 and 61. These crystals are easily decomposed by sulfuric acid, the well-known long prismatic crystals of gypsum taking their place. On treatment of silt particles containing lime with hydrofluoric and sulfuric acids, only a part of the lime passes into solution if the content thereof be large. Where but little lime is present and the sulfuric acid is in large excess, all the lime passes into solution and the characteristic gypsum crystals appear as in Fig. 62.



FIGURE 56.



FIGURE 57.

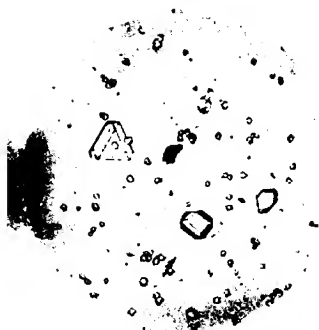


FIGURE 58.



FIGURE 59.

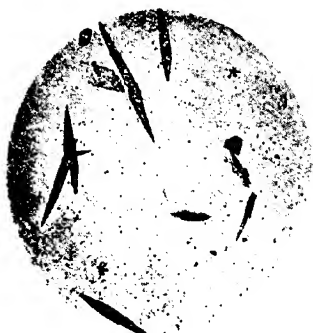


FIGURE 60.



FIGURE 61.

Figure 56. Sodium and aluminum silicofluoride crystals magnified 100, 140 and 160 diameters.

Figure 57. Potassium silicofluoride crystals magnified 130 diameters.

Figure 58. Another preparation of the same magnified 140 diameters.

Figure 59. Lithium and aluminum silicofluoride crystals magnified 100 diameters.

Figure 60. Calcium silicofluoride crystals magnified 45 diameters.

Figure 61. Another preparation of the same magnified 42 diameters.

